US005396584A

# United States Patent [19]

Lee et al.

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[45] Date of Patent: Mar. 7, 1995

[54] **MULTI-BIT IMAGE EDGE ENHANCEMENT METHOD AND APPARATUS**

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[21] Appl. No.: **892,062**

[22] Filed: **May 29, 1992**

[51] **Int. Cl.**[6] ..... **G06F 15/62**

[52] **U.S. Cl.** ..... **395/132;** 395/128; 395/129

[58] **Field of Search** ..... 395/132, 126–130, 395/150, 151; 358/443, 455–459, 461, 298

[56] **References Cited**

U.S. PATENT DOCUMENTS

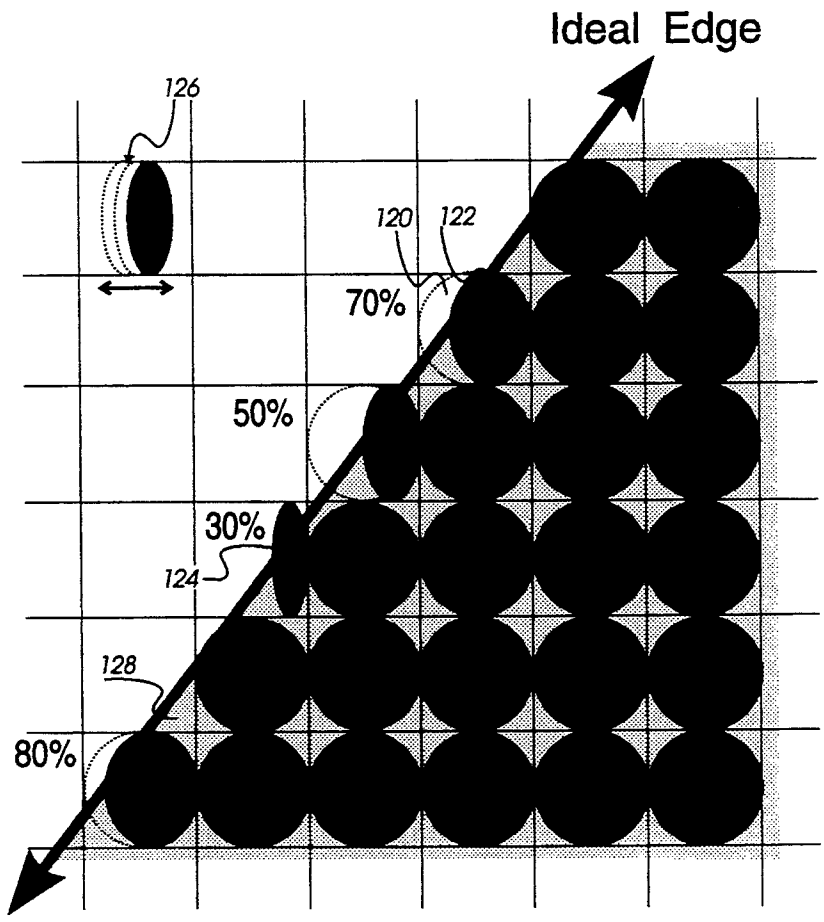
5,029,108 7/1991 Lung ..... 395/132

*Primary Examiner*—Almis Jankus
*Attorney, Agent, or Firm*—Claude A. S. Hamrick

[57] **ABSTRACT**

Multi-bit image edge enhancement method and apparatus wherein a group of gradient mask matrices are applied to a "current matrix", wherein a TBAP (To Be Adjusted Pixel) is surrounded by neighboring pixels, to determine if the TBAP is at a location where a change of brightness occurs. From this matrix operation, a conclusion is derived as to the existence or non-existence of an edge and the direction of the brightness change. The current matrix and a predetermined number of previously evaluated and yet to be evaluated pixels are then compared to a set of reference bit patterns which depict possible segment changes to be corrected. If the result indicates that the TBAP is on an edge of a changing edge segment, a corresponding code will be generated to modify the TBAP to enhance the smoothness of a segment transition. In the case of an electrophotographic or a gray scale printing machine, the specific code will change either the location or the size of the TBAP; whereas in the case of a monochrome screen display, the specific code will change the intensity of the TBAP.

**38 Claims, 25 Drawing Sheets**



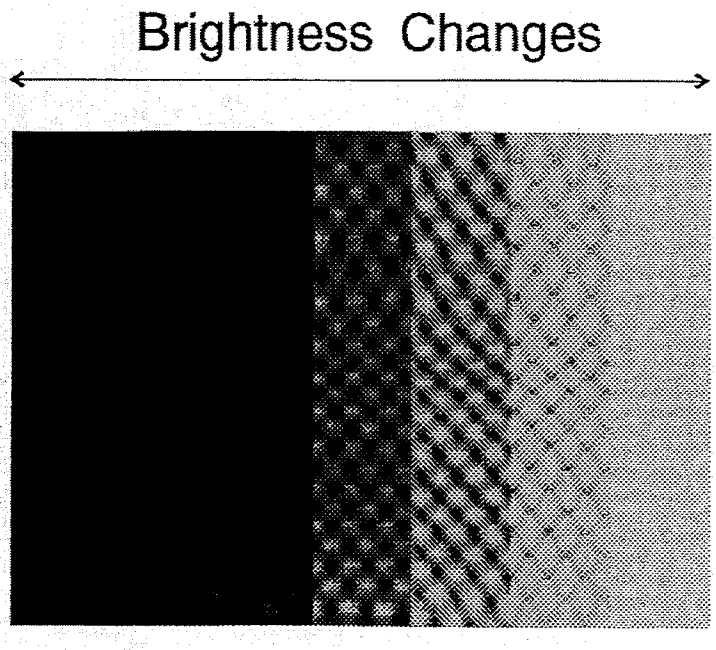

Brightness Changes

FIG. 1a

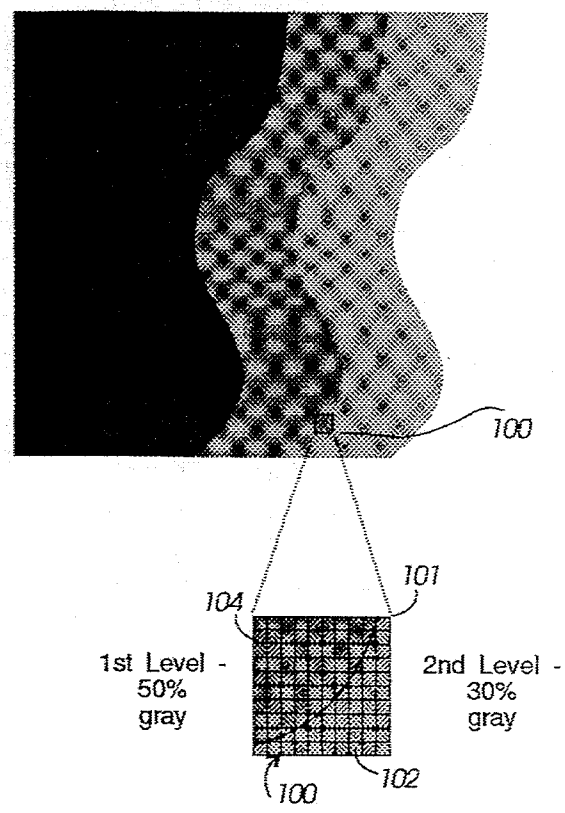

100
101
104
1st Level - 50% gray
2nd Level - 30% gray
102
100

FIG. 1b

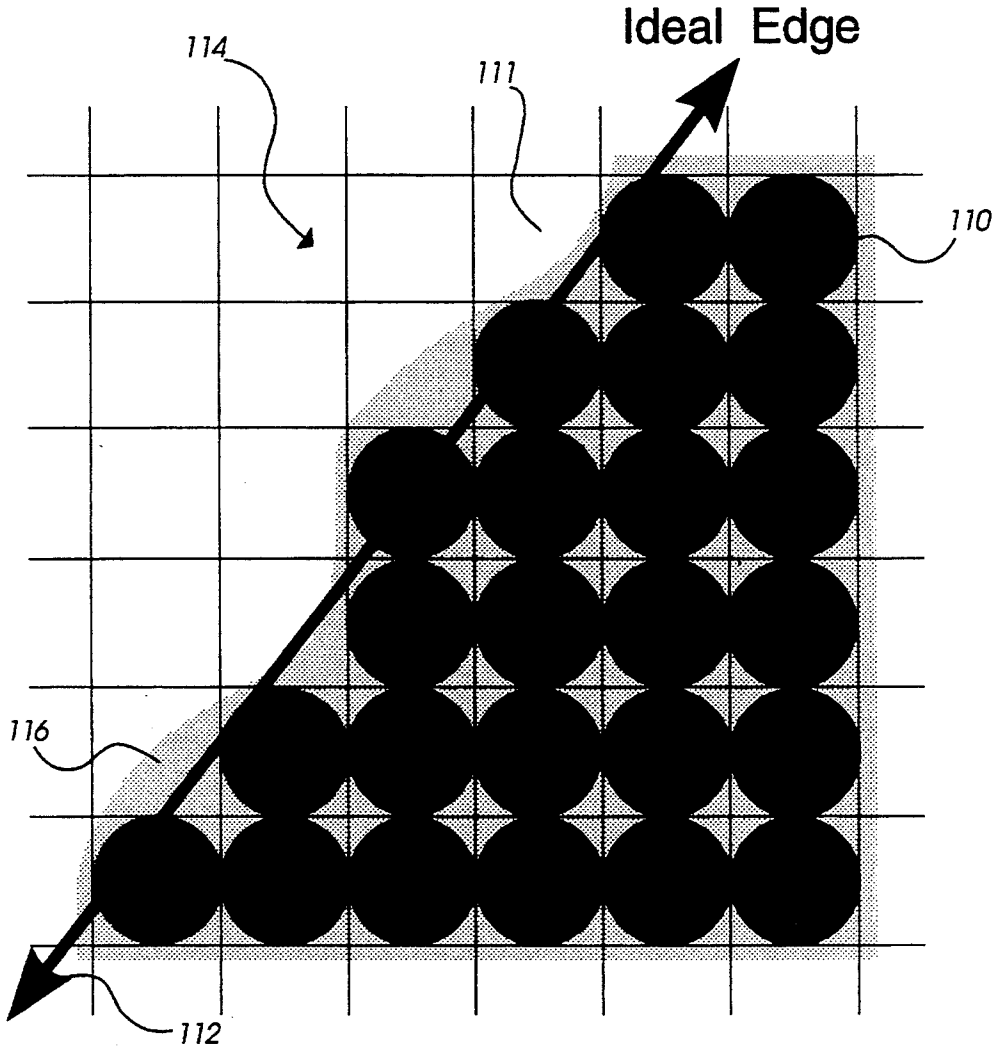



FIG. 2a

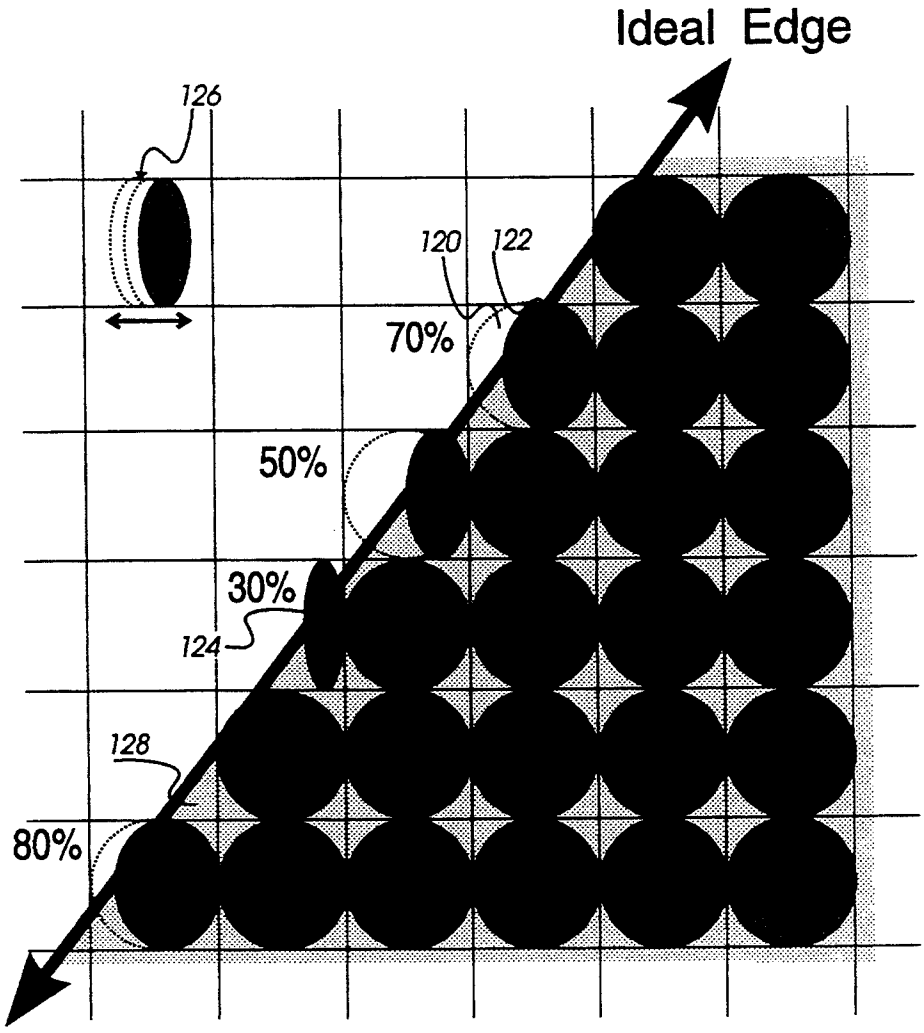
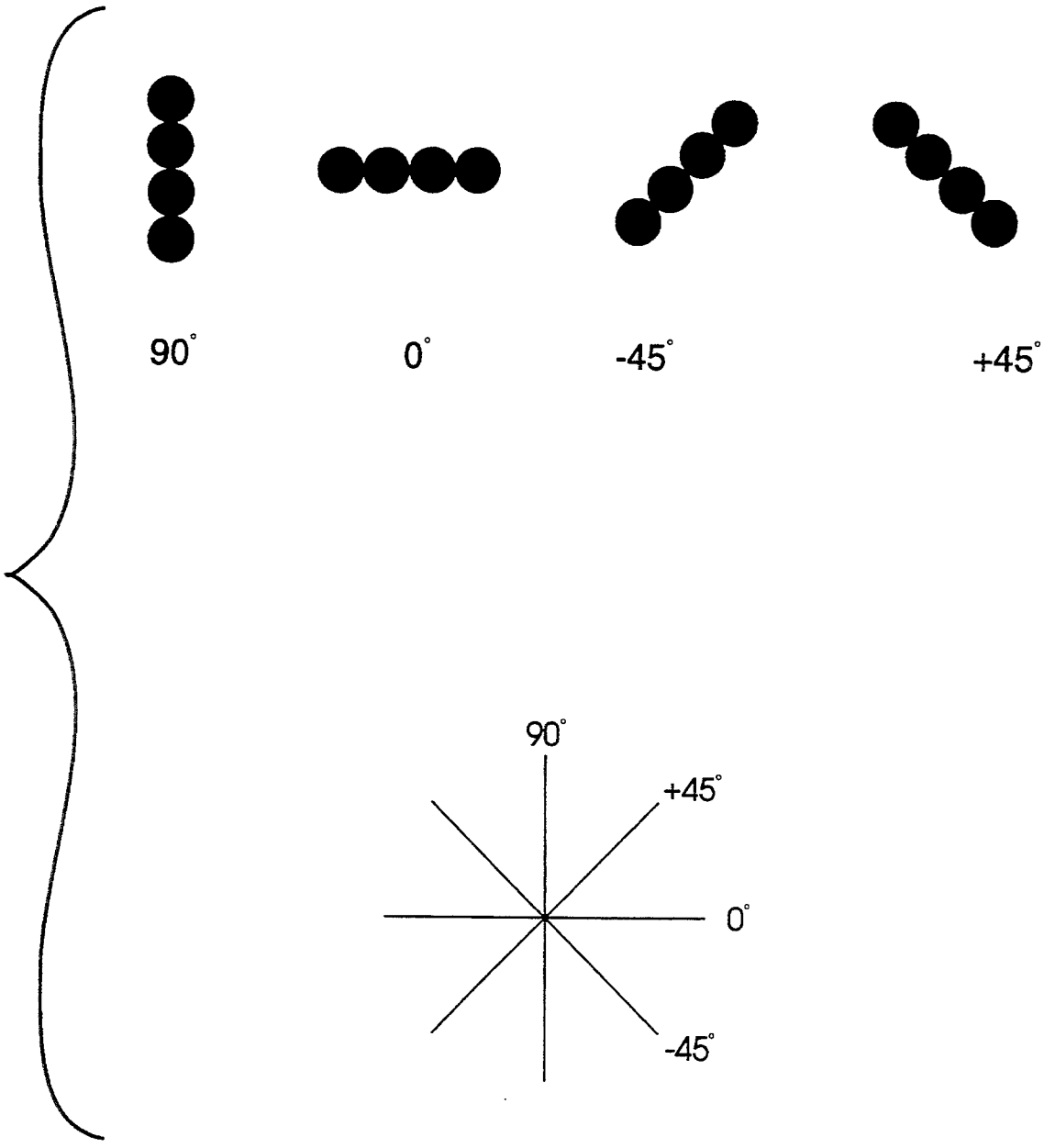



FIG. 2b

# FIG. 3a



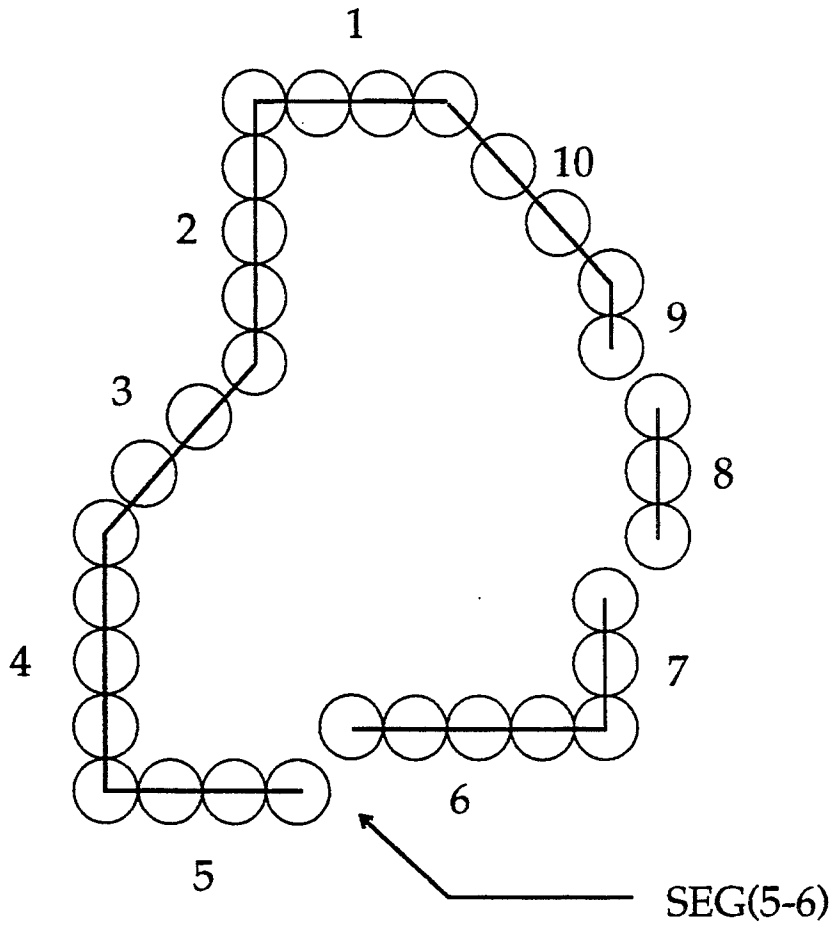



FIG. 3b

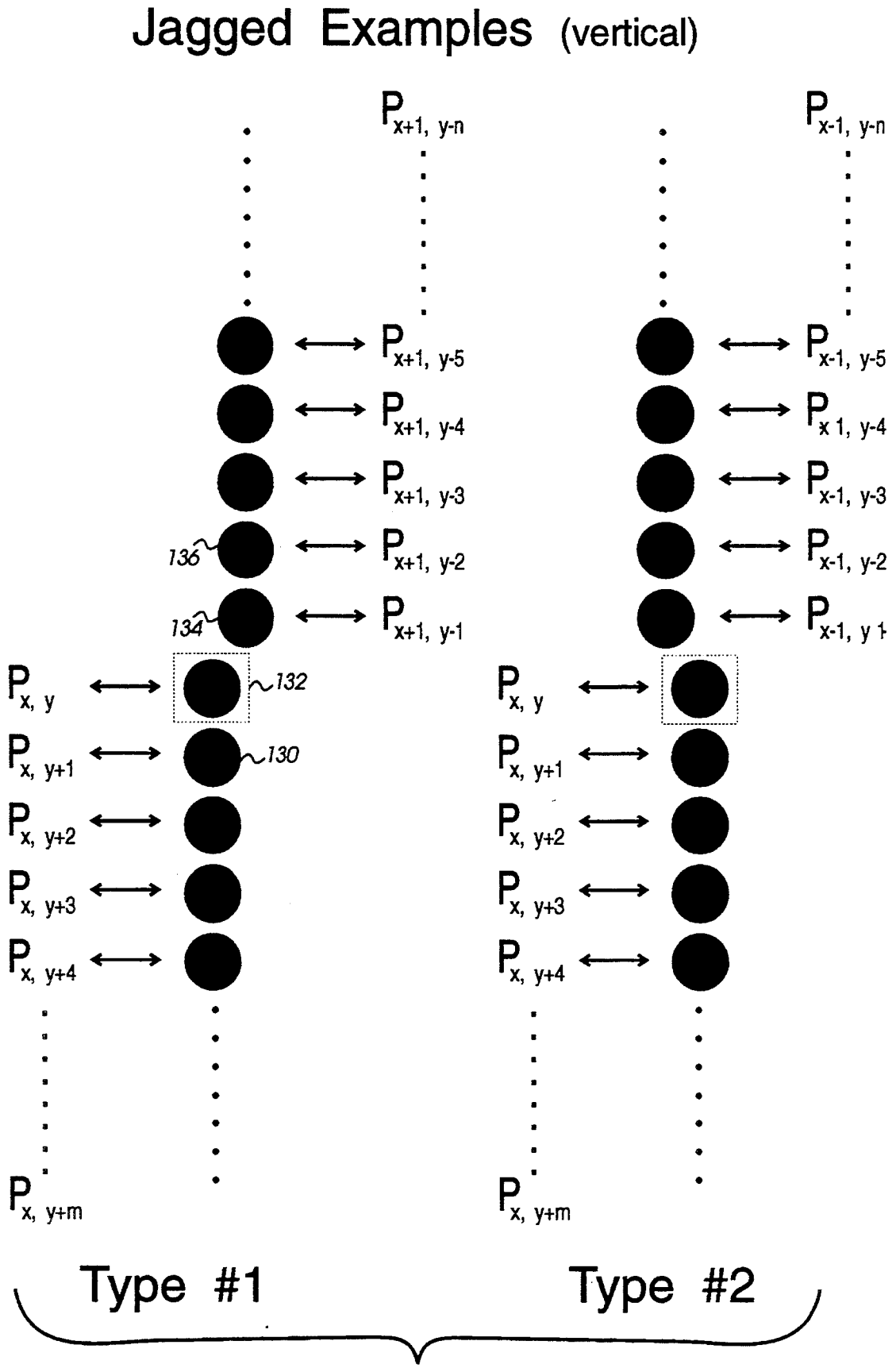

Jagged Examples (vertical)
$P_{x+1, y-n}$
$P_{x+1, y-5}$
$P_{x+1, y-4}$
$P_{x+1, y-3}$
$P_{x+1, y-2}$
$P_{x+1, y-1}$
136
134
132
130
$P_{x, y}$
$P_{x, y+1}$
$P_{x, y+2}$
$P_{x, y+3}$
$P_{x, y+4}$
$P_{x, y+m}$
$P_{x-1, y-n}$
$P_{x-1, y-5}$
$P_{x-1, y-4}$
$P_{x-1, y-3}$
$P_{x-1, y-2}$
$P_{x-1, y-1}$
$P_{x, y}$
$P_{x, y+1}$
$P_{x, y+2}$
$P_{x, y+3}$
$P_{x, y+4}$
$P_{x, y+m}$
Type #1
Type #2

FIG. 4a

EET EXAMPLE: VERTICAL SEGMENT

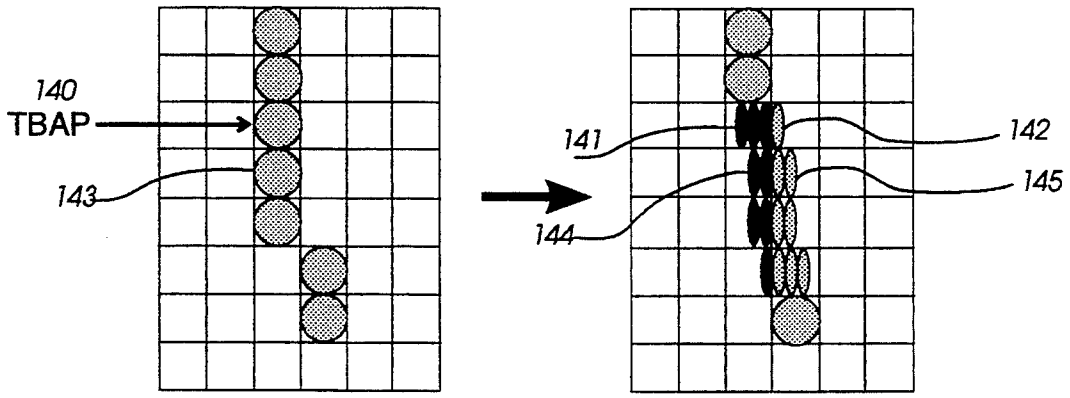



FIG. 4b

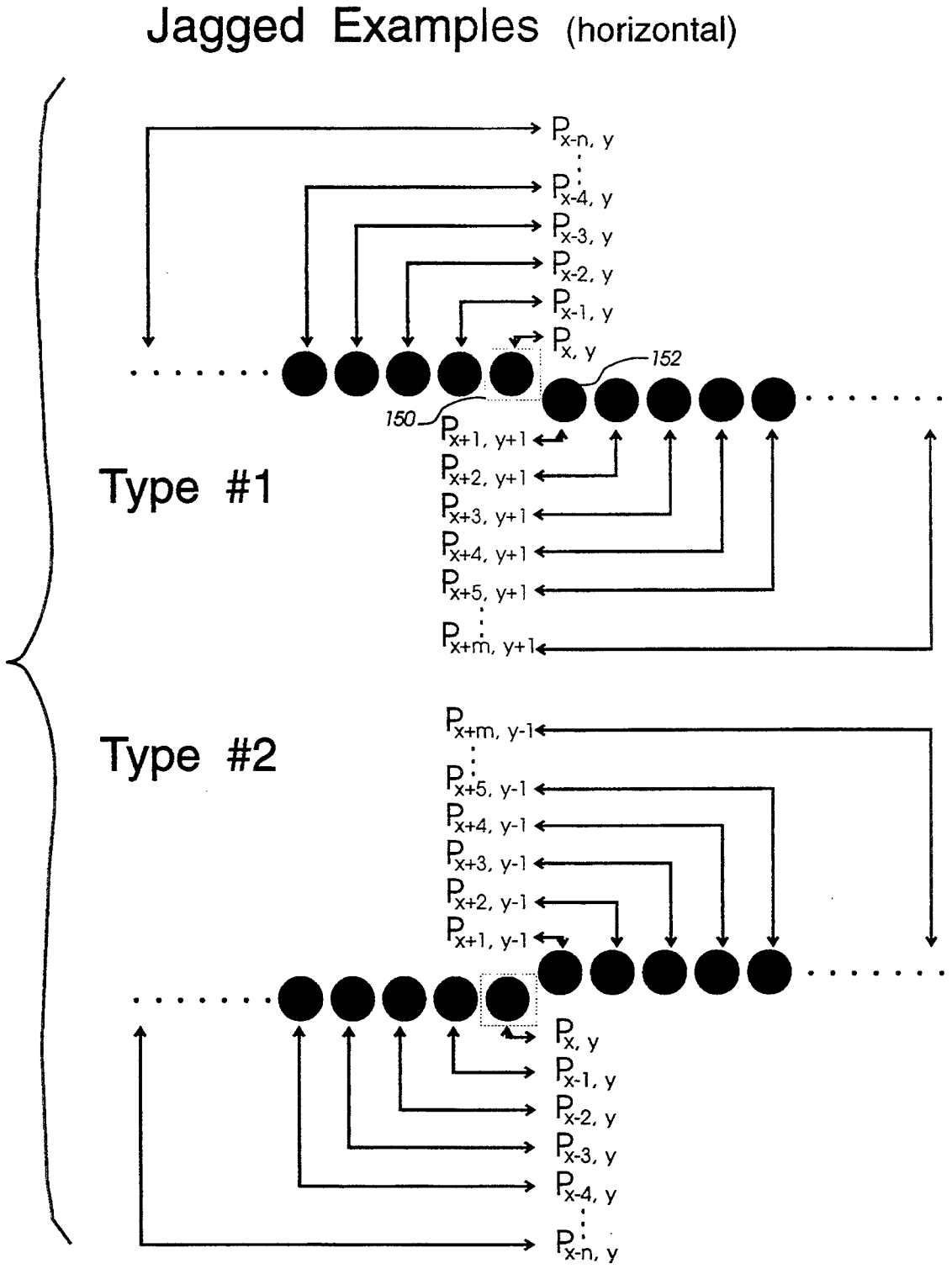

Jagged Examples (horizontal)
Type #1
Type #2
$P_{x-n, y}$
$P_{x-4, y}$
$P_{x-3, y}$
$P_{x-2, y}$
$P_{x-1, y}$
$P_{x, y}$
152
150
$P_{x+1, y+1}$
$P_{x+2, y+1}$
$P_{x+3, y+1}$
$P_{x+4, y+1}$
$P_{x+5, y+1}$
$P_{x+m, y+1}$
$P_{x+m, y-1}$
$P_{x+5, y-1}$
$P_{x+4, y-1}$
$P_{x+3, y-1}$
$P_{x+2, y-1}$
$P_{x+1, y-1}$
$P_{x, y}$
$P_{x-1, y}$
$P_{x-2, y}$
$P_{x-3, y}$
$P_{x-4, y}$
$P_{x-n, y}$

FIG. 5a

EET EXAMPLE: HORIZONTAL SEGMENT

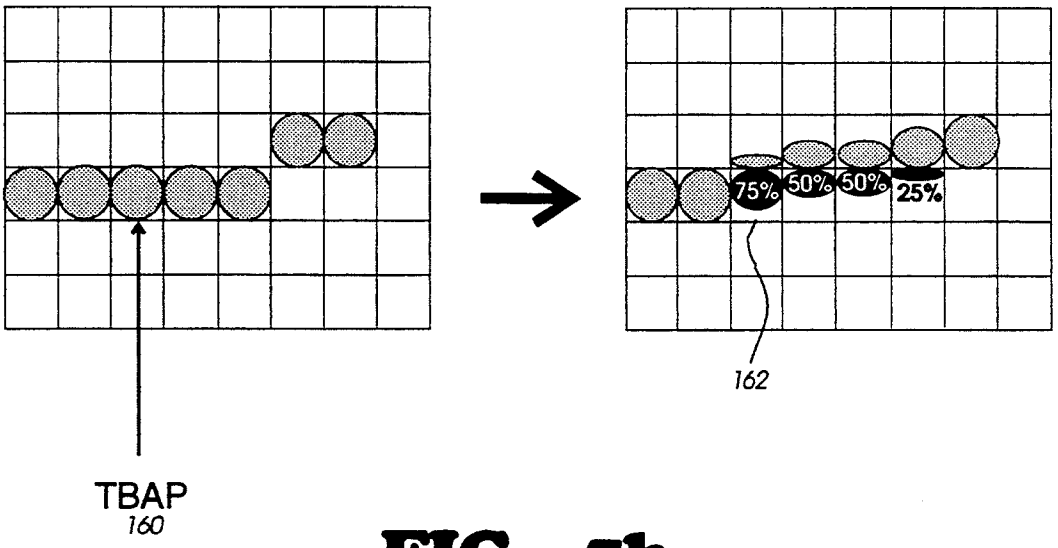



FIG. 5b

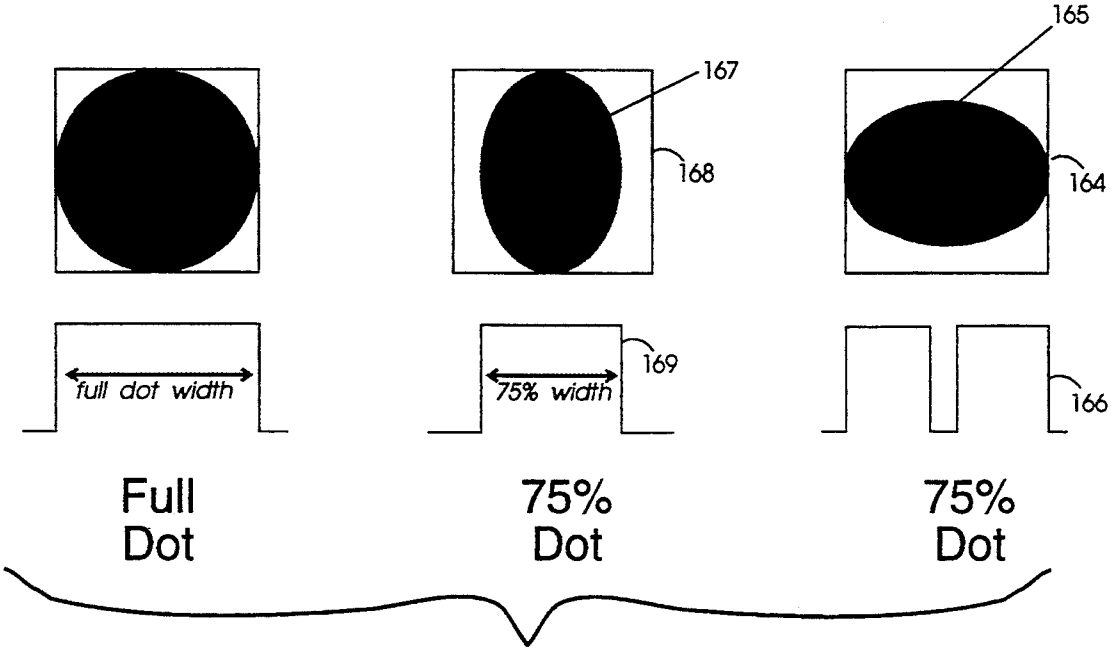
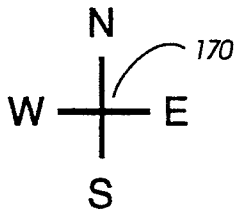



FIG. 6

# FIG. 7a




## Gradient Mask

bitmap pattern

| | | |
|---|---|---|
| p(x-1,y-1) | p(x,y-1) | p(x+1,y-1) |
| p(x-1,y) | p(x,y) | p(x+1,y) |
| p(x-1,y+1) | p(x,y+1) | p(x+1,y+1) |

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*

gradient mask

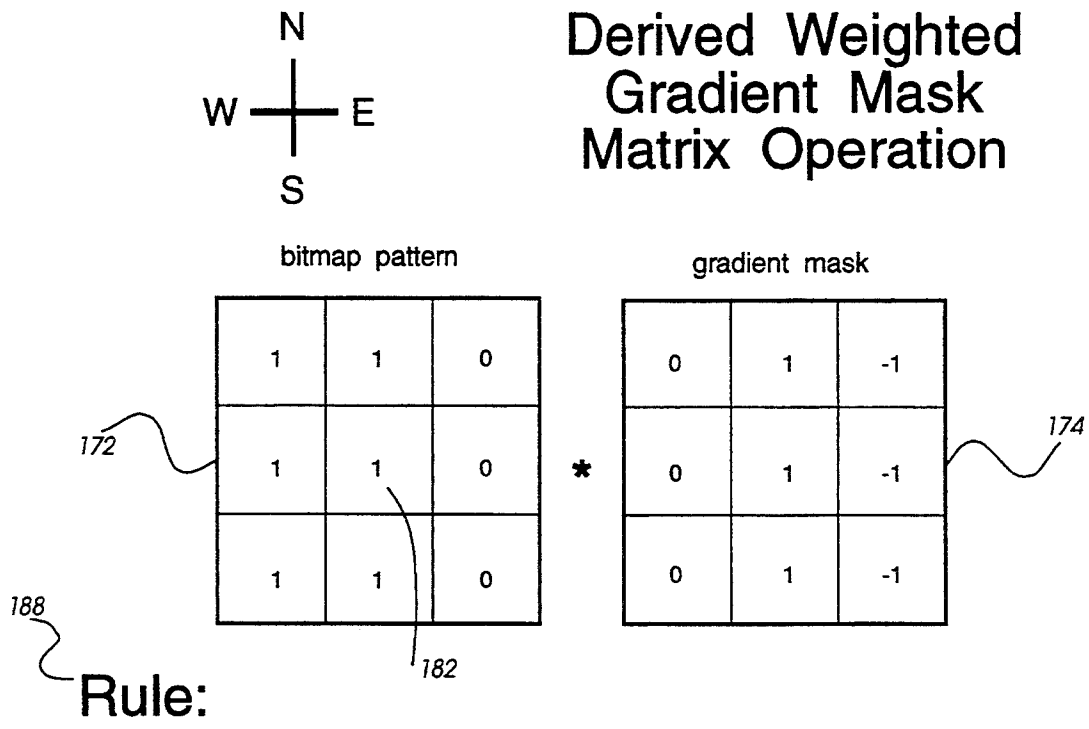
| | | |
|---|---|---|
| q(x-1,y-1) | q(x,y-1) | q(x+1,y-1) |
| q(x-1,y) | q(x,y) | q(x+1,y) |
| q(x-1,y+1) | q(x,y+1) | q(x+1,y+1) |

174

Whereas "*" denotes the spatial convolution operator

(bitmap pattern) * (gradient mask)
= p(x-1, y-1) • q(x-1, y-1) + p(x, y-1) • q(x, y-1) + p(x+1, y-1) • q(x+1, y-1)
+ p(x-1, y) • q(x-1, y) + p(x, y) • q(x, y) + p(x+1, y) • q(x+1, y)
+ p(x-1, y+1) • q(x-1, y+1) + p(x, y+1) • q(x, y+1) + p(x+1, y+1) • q(x+1, y+1)

# FIG. 7b




1. (-1) denotes "inverter" in logic circuit, or NOT in boolean expression
2. (a • b) denotes (a AND b) in boolean expression
3. When b=(-1), (a • b) ⇒ (¬a)

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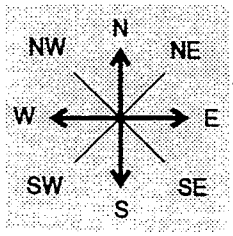
Result from example above:

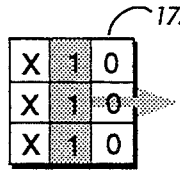
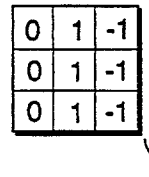
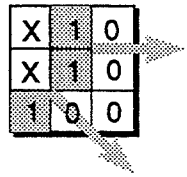
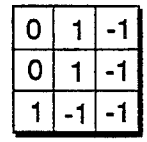
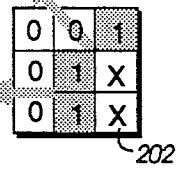
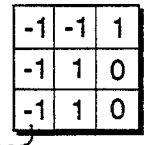
(1)•(0) + (1)•(1) + (0)•(-1) + (1)•(0) + (1)•(1) + (0)•(-1) + (1)•(0) + (1)•(1) + (0)•(-1)
= 0 + 1 + (¬0) + 0 + 1 + (¬0) + 0 + 1 + (¬0)
= 0 + 1 + 1 + 0 + 1 + 1 + 0 + 1 + 1
= 6

∴ Gradient toward East exists.
This TBAP is defined to be on the East Segment (E-Seg).

# FIG. 8a

GRADIENT MASK
(Examples of Vertical Segment)




| | Pattern | Gradient Mask | Detection Condition |
|---|---|---|---|
| 1. East Segment (E-Seg) |  |  | 6 |
| 2. East-SouthEast Segment (ESE-Seg) |  |  | 7 |
| 3. NorthWest-West Segment (NWW-Seg) |  |  | 7 |

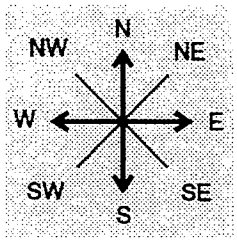


Note:

1. (-1) in Gradient Mask means "Inverter" in logic circuit.
2. * means spatial convolution.
3. X means "*don't care*" (either 0 or 1).
4. ⟶ means brightness change.

# FIG. 8b

GRADIENT MASK
(Examples of Horizontal Segment)




| | Pattern | | Gradient Mask | | Detection Condition |
|---|---|---|---|---|---|
| 1. North Segment (N-Seg) | 0 0 0<br>1 1 1<br>X X X | * | -1 -1 -1<br>1 1 1<br>0 0 0 | = | 6 |
| 2. South-SouthWest Segment (SSW-Seg) | 1 1 X<br>0 0 1<br>0 0 0 | * | 1 1 0<br>-1 -1 1<br>-1 -1 -1 | = | 8 |
| 3. SouthEast-South Segment (SES-Seg) | X X 1<br>1 1 0<br>0 0 0 | * | 0 0 1<br>1 1 -1<br>-1 -1 -1 | = | 7 |

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Note:

1. (-1) in Gradient Mask means "Inverter" in logic circuit.
2. * means spatial convolution.
3. X means "*don't care*" (either 0 or 1).
4. ⟶ means brightness change.

**FIG. 9a**

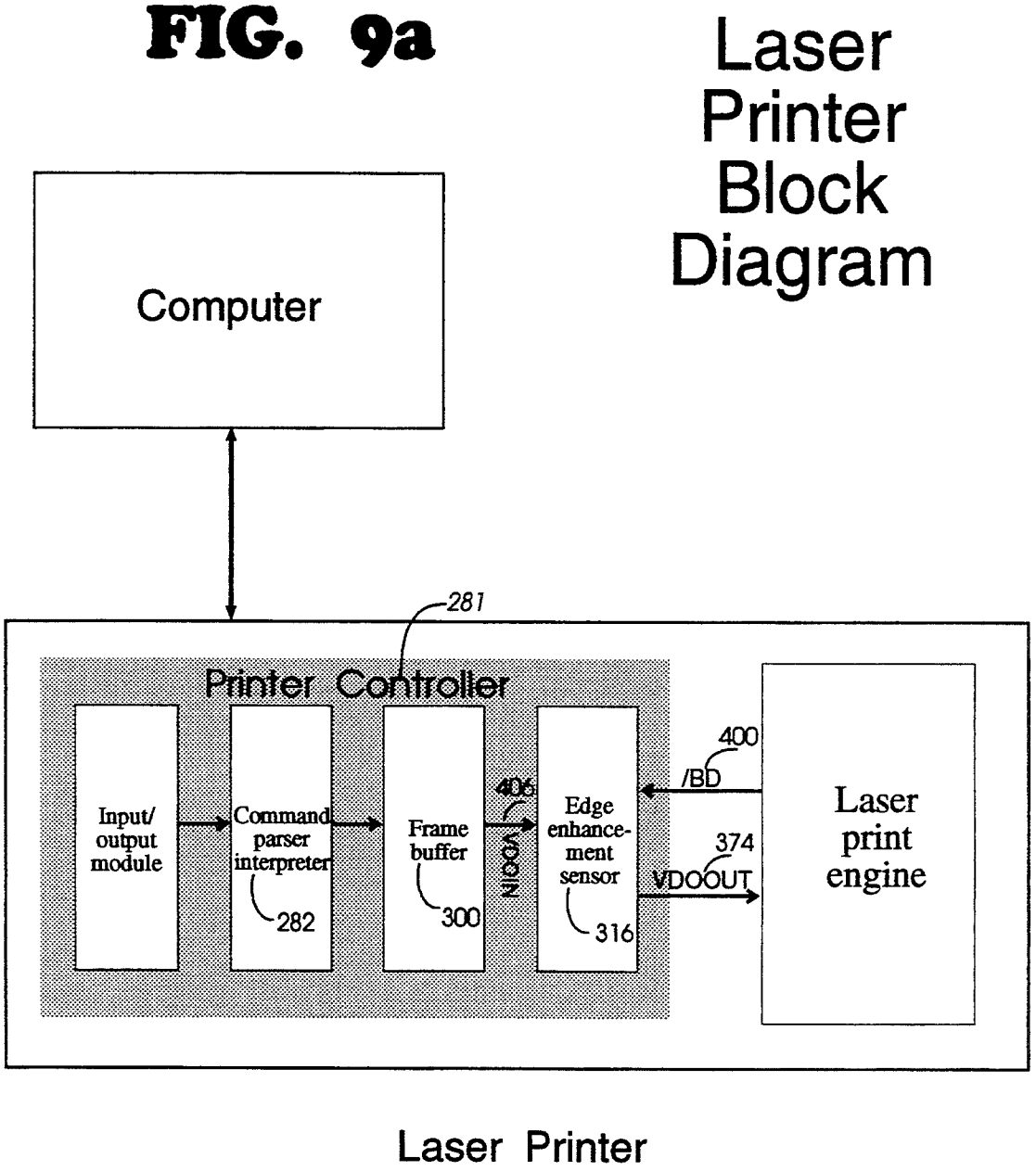
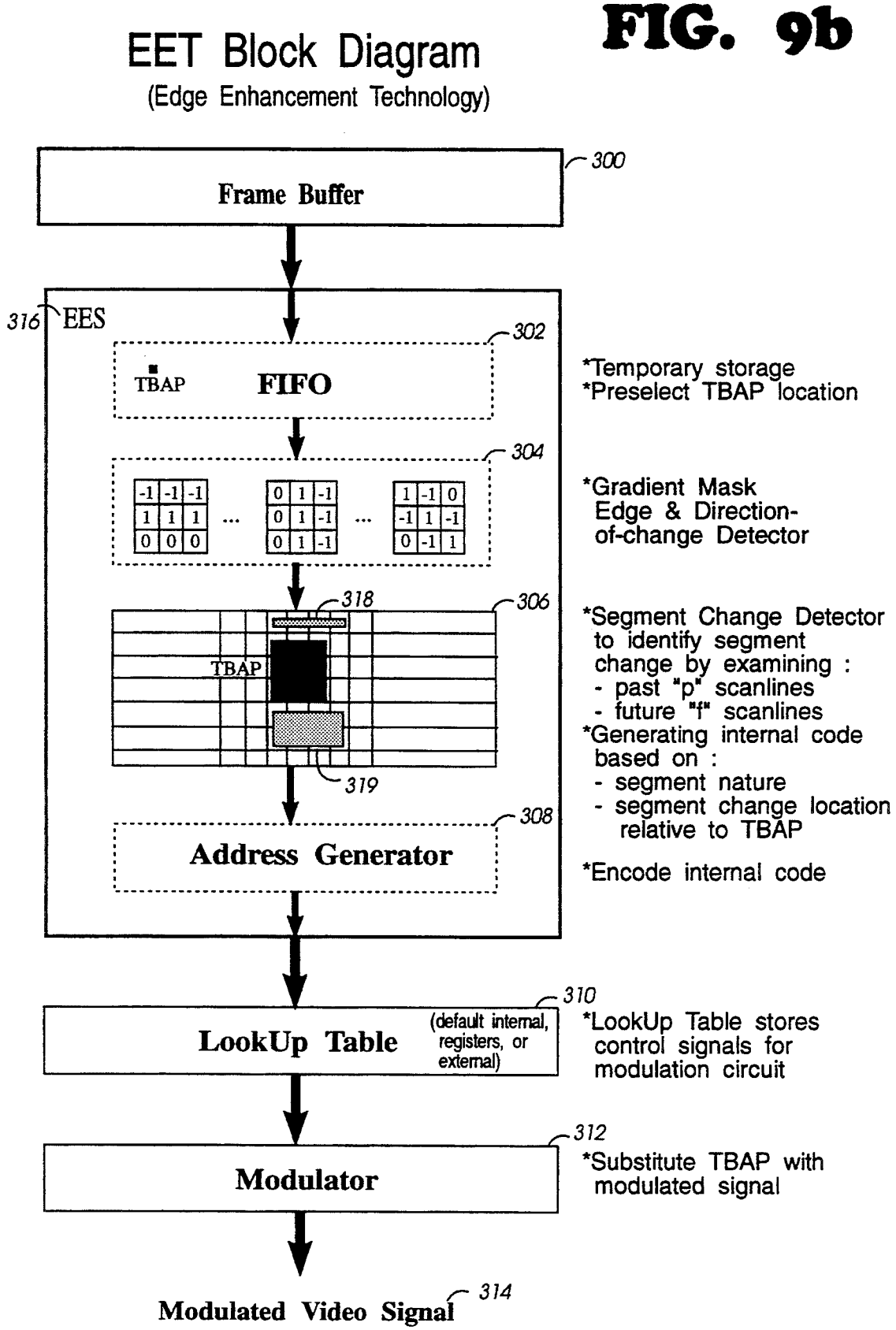

Laser Printer Block Diagram
Computer
281
Printer Controller
Input/ output module
Command parser interpreter
282
Frame buffer
300
406
VDOIN
Edge enhance-ment sensor
316
400
/BD
374
VDOOUT
Laser print engine
Laser Printer

FIG. 9b


EET Block Diagram
(Edge Enhancement Technology)
Frame Buffer
300
316
EES
302
TBAP
FIFO
*Temporary storage
*Preselect TBAP location
304
-1 -1 -1
1 1 1
0 0 0
0 1 -1
0 1 -1
0 1 -1
1 -1 0
-1 1 -1
0 -1 1
*Gradient Mask
Edge & Direction-
of-change Detector
318
306
TBAP
319
*Segment Change Detector
to identify segment
change by examining :
- past "p" scanlines
- future "f" scanlines
*Generating internal code
based on :
- segment nature
- segment change location
relative to TBAP
308
Address Generator
*Encode internal code
310
LookUp Table
(default internal, registers, or external)
*LookUp Table stores
control signals for
modulation circuit
312
Modulator
*Substitute TBAP with
modulated signal
Modulated Video Signal
314

# Edge Enhancement Logic Flow

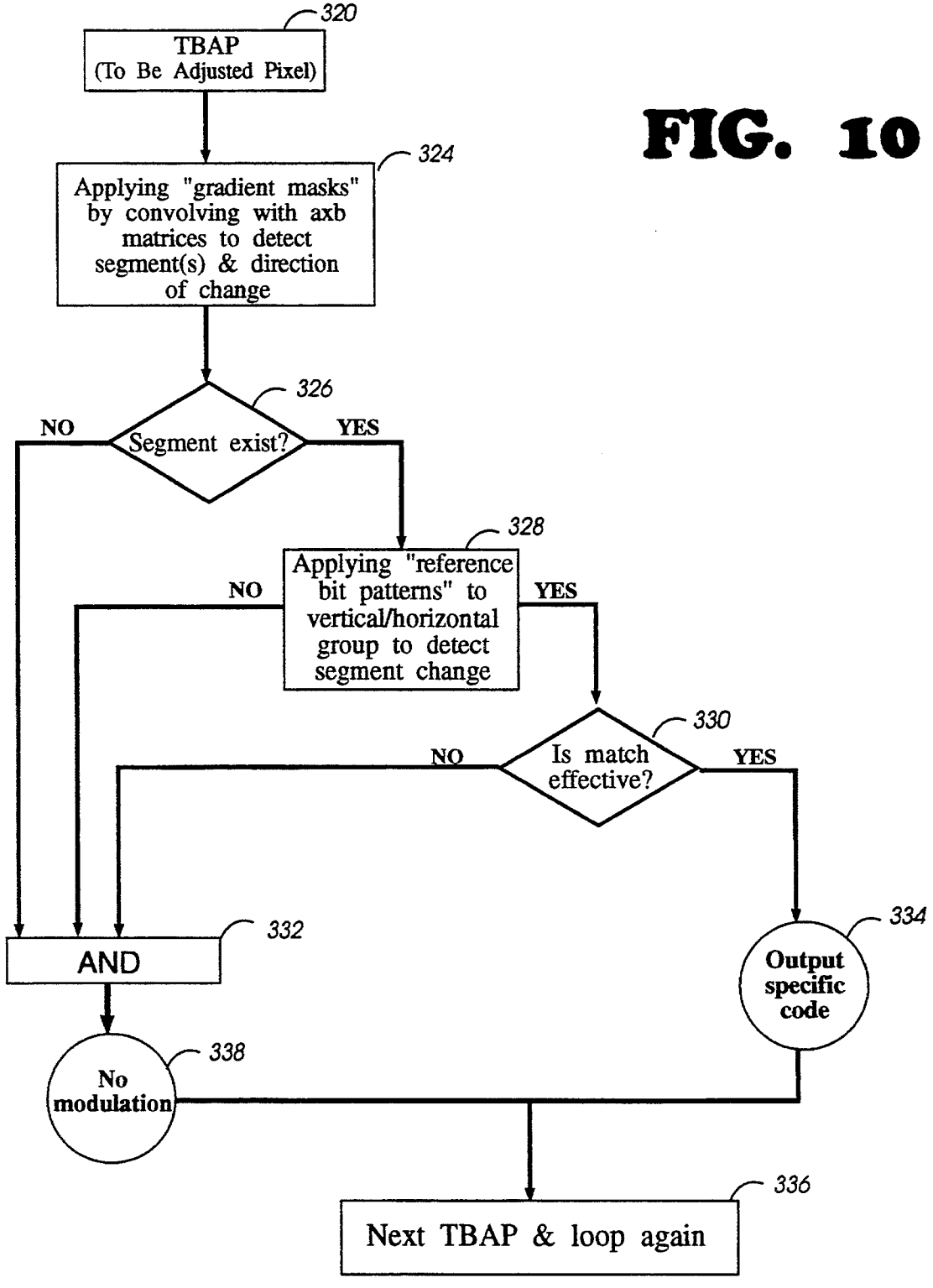
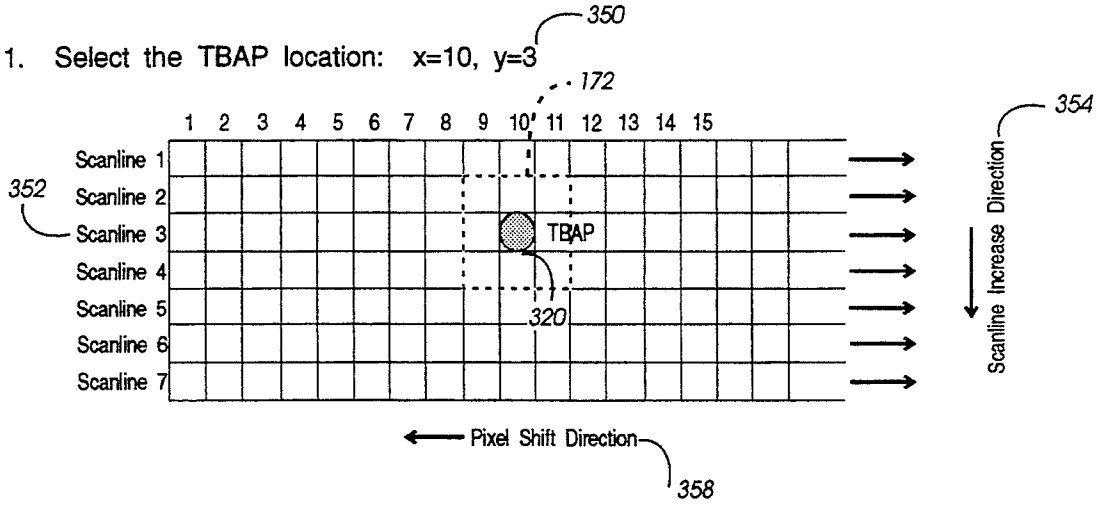



FIG. 10

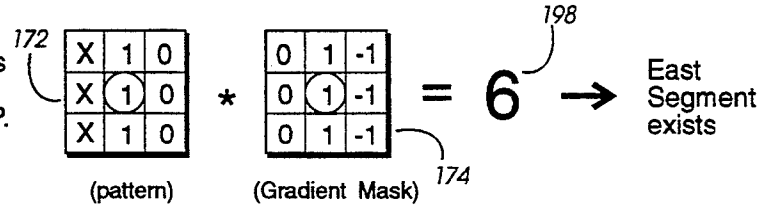
# FIG. 11

## EET EXAMPLE: VERTICAL SEGMENT

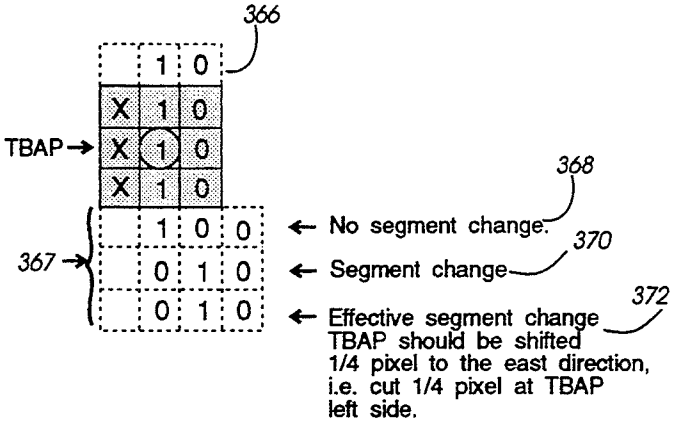
1. Select the TBAP location: x=10, y=3




2. TBAP = 1, apply Gradient Masks to check if segment existing around TBAP.




3. Check the "segment change" in the range: (a) one more scan line in the past, (b) two more scan lines in the future, along the E-Seg direction.




4. Segment change being detected, generate a specific code to Address Generator based on the segment type and segment change location relative to TBAP location.

5. Address Generator encodes the specific code, generates address to Lookup ROM.

6. Lookup ROM outputs control signals to Modulation Logic.

7. Modulate TBAP according to the control signals.

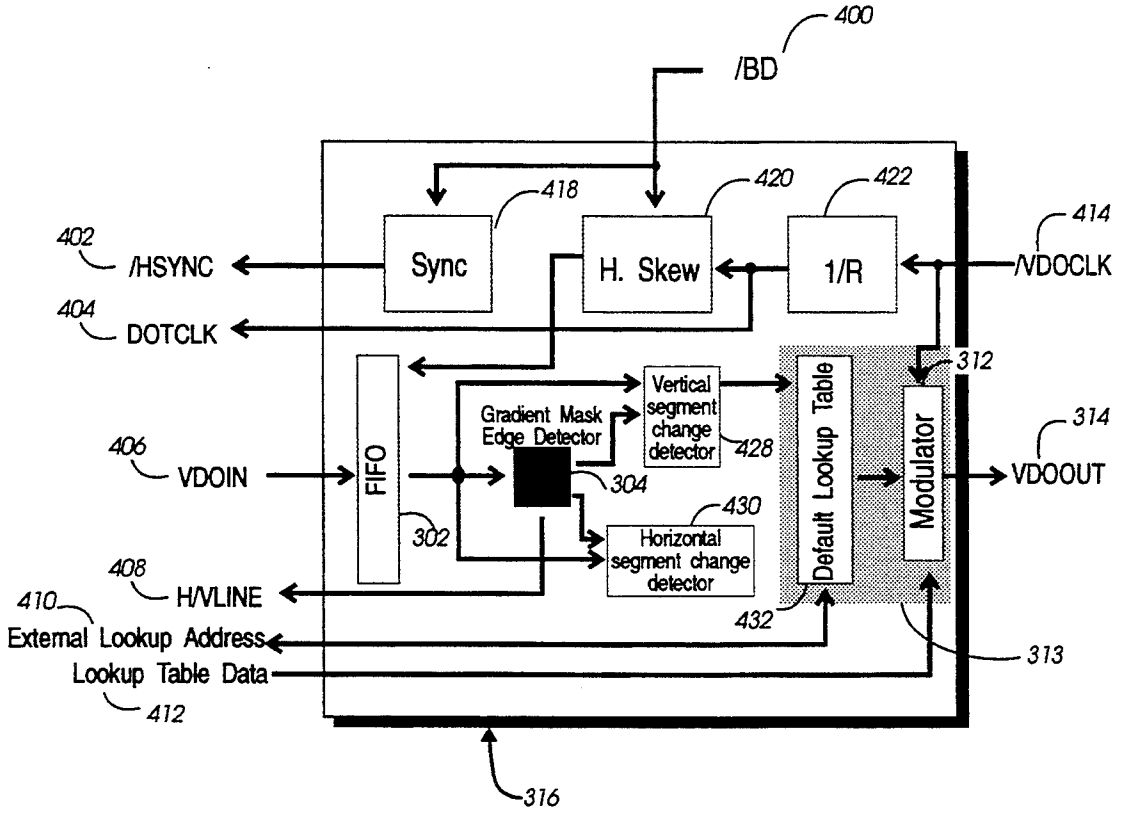

Destiny EET ASIC
Block Diagram
400
/BD
418
420
422
414
402
/HSYNC
Sync
H. Skew
1/R
/VDOCLK
404
DOTCLK
312
Vertical segment change detector
428
Gradient Mask Edge Detector
314
406
VDOIN
FIFO
304
VDOOUT
430
302
Horizontal segment change detector
Default Lookup Table
Modulator
408
H/VLINE
410
External Lookup Address
432
313
Lookup Table Data
412
316

FIG. 12

# Pulse Width Modulation Logic Diagram

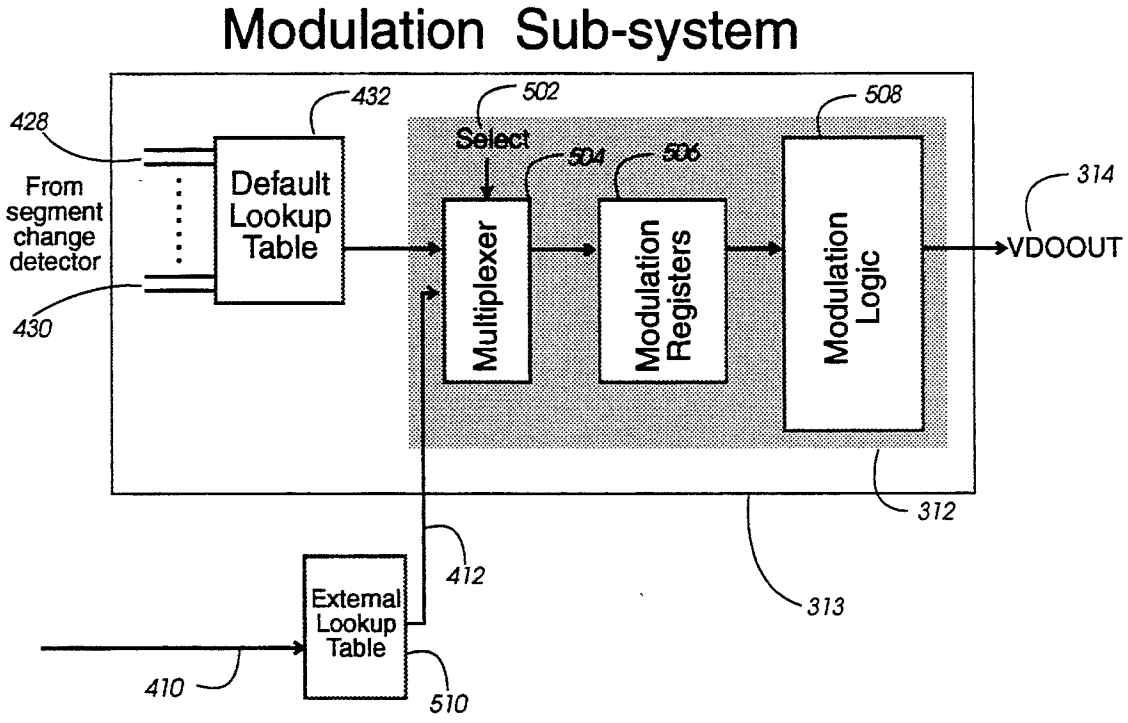



FIG. 13

One full-size dot is divided into 16 subdots.

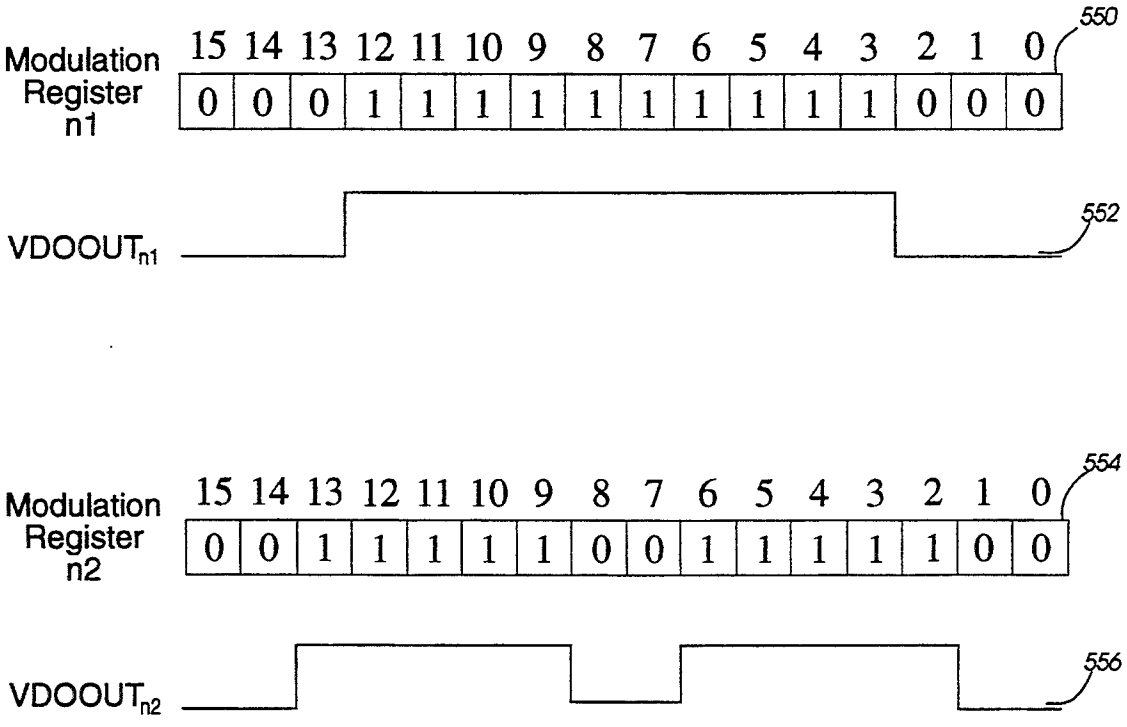


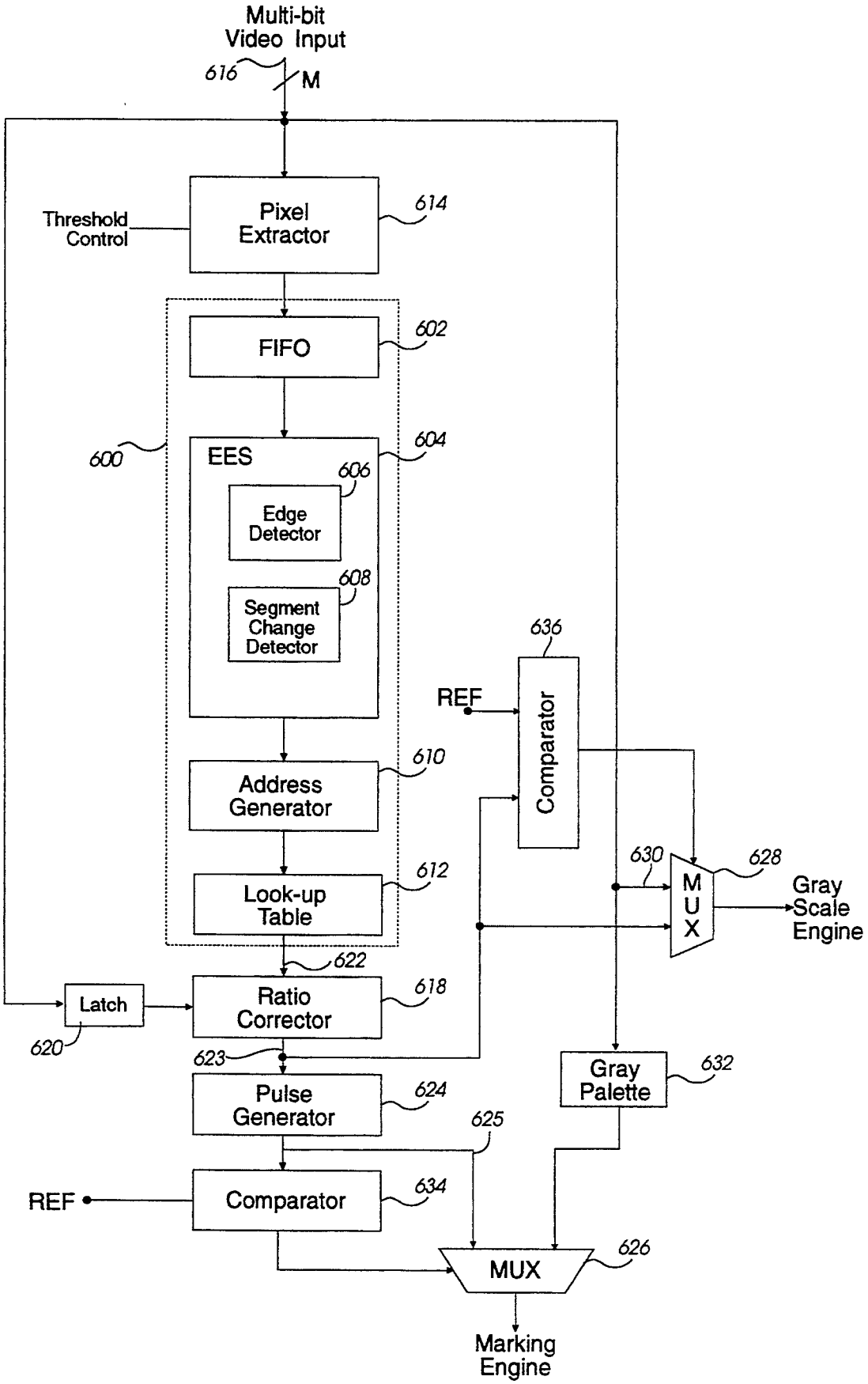

FIG. 14

## Dot Modulation Registers 506

| Modulation Register | Instruction | Address Code | Item |
|---|---|---|---|
| Shift Left 1/4 Dot | MSL1/4 | 04h | 1 |
| Shift Left 2/4 Dot | MSL2/4 | 05h | 2 |
| Shift Left 3/4 Dot | MSL3/4 | 06h | 3 |
| Shift Right 1/4 Dot | MSR1/4 | 07h | 4 |
| Shift Right 2/4 Dot | MSR2/4 | 08h | 5 |
| Shift Right 3/4 Dot | MSR3/4 | 09h | 6 |
| (Light) Dot Size 1/4 | LDS1/4 | 0Ah | 7 |
| (Light) Dot Size 2/4 | LDS2/4 | 0Bh | 8 |
| (Light) Dot Size 3/4 | LDS3/4 | 0Ch | 9 |
| (Medium) Dot Size 1/4 | MDS1/4 | 0Dh | 10 |
| (Medium) Dot Size 2/4 | MDS2/4 | 0Eh | 11 |
| (Medium) Dot Size 3/4 | MDS3/4 | 0Fh | 12 |
| (Dark) Dot Size 1/4 | DDS1/4 | 10h | 13 |
| (Dark) Dot Size 2/4 | DDS2/4 | 11h | 14 |
| (Dark) Dot Size 3/4 | DDS3/4 | 12h | 15 |

FIG. 15

FIG. 16


Multi-bit
Video Input
616
M
Threshold
Control
Pixel
Extractor
614
FIFO
602
600
EES
604
606
Edge
Detector
608
Segment
Change
Detector
636
REF
Comparator
Address
Generator
610
630
628
612
Look-up
Table
M
U
X
Gray
Scale
Engine
622
Latch
Ratio
Corrector
618
620
623
Gray
Palette
632
Pulse
Generator
624
625
REF
Comparator
634
MUX
626
Marking
Engine

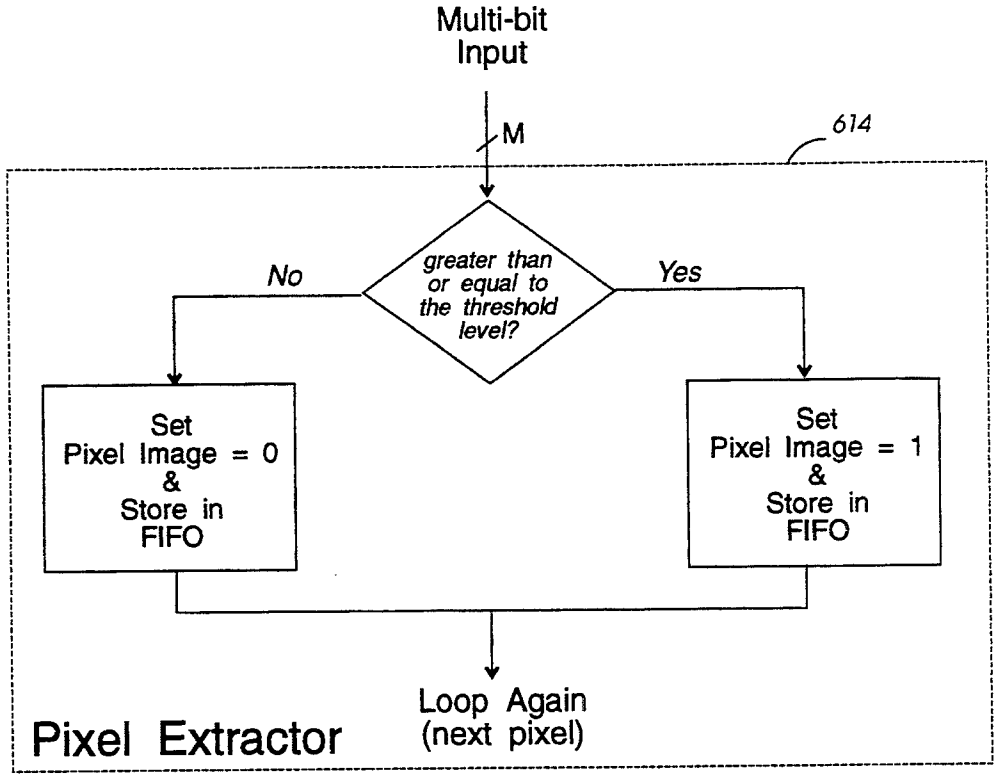

Multi-bit
Input
M
614
greater than
or equal to
the threshold
level?
No
Yes
Set
Pixel Image = 0
&
Store in
FIFO
Set
Pixel Image = 1
&
Store in
FIFO
Loop Again
(next pixel)
Pixel Extractor

FIG. 17

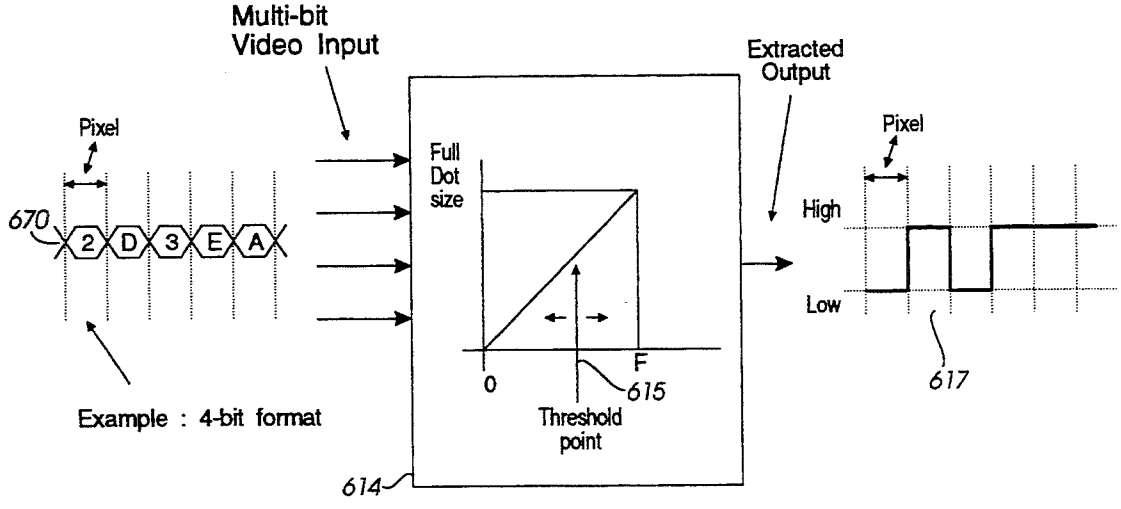

Multi-bit
Video Input
Extracted
Output
Pixel
670
2
D
3
E
A
Example : 4-bit format
Full
Dot
size
0
F
615
Threshold
point
614
Pixel
High
Low
617

FIG. 18

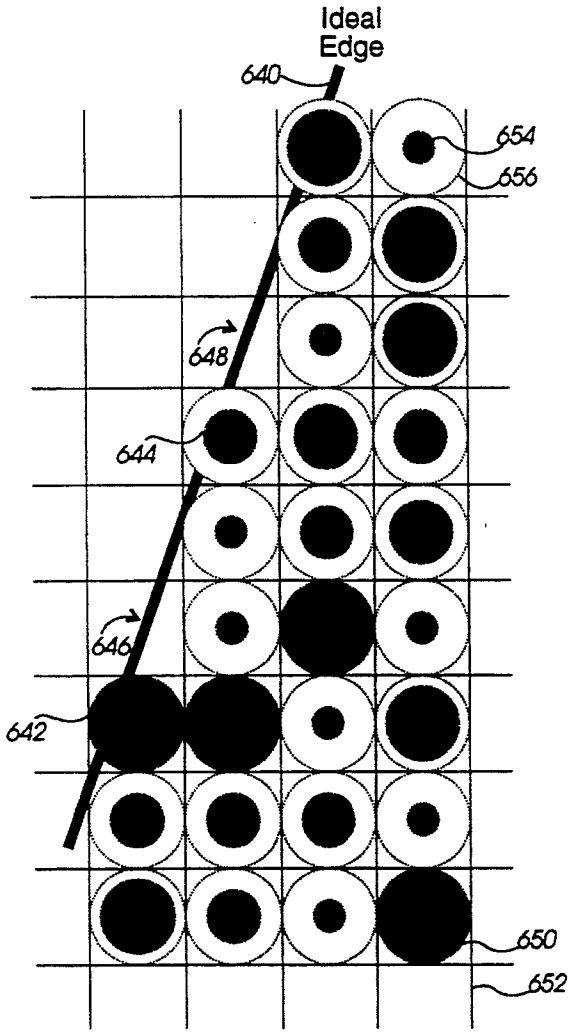



FIG. 19a

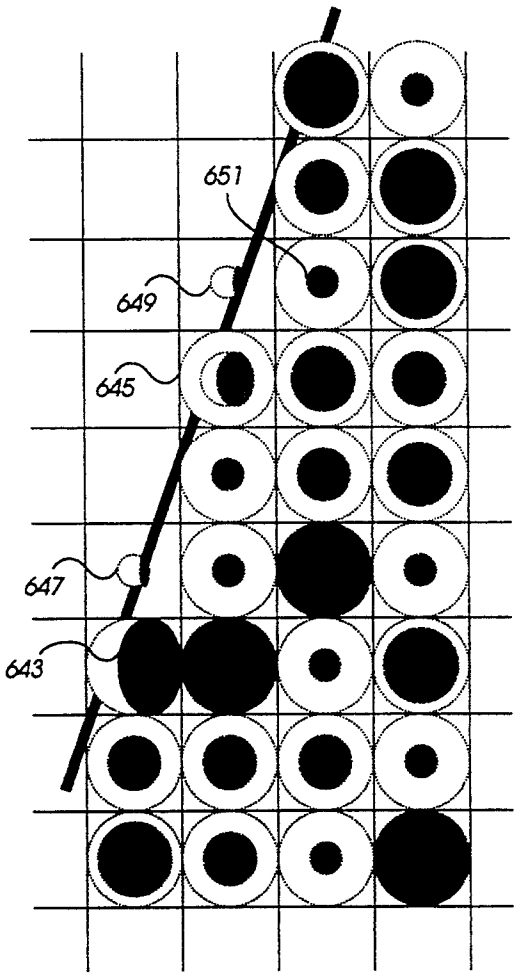



FIG. 19b

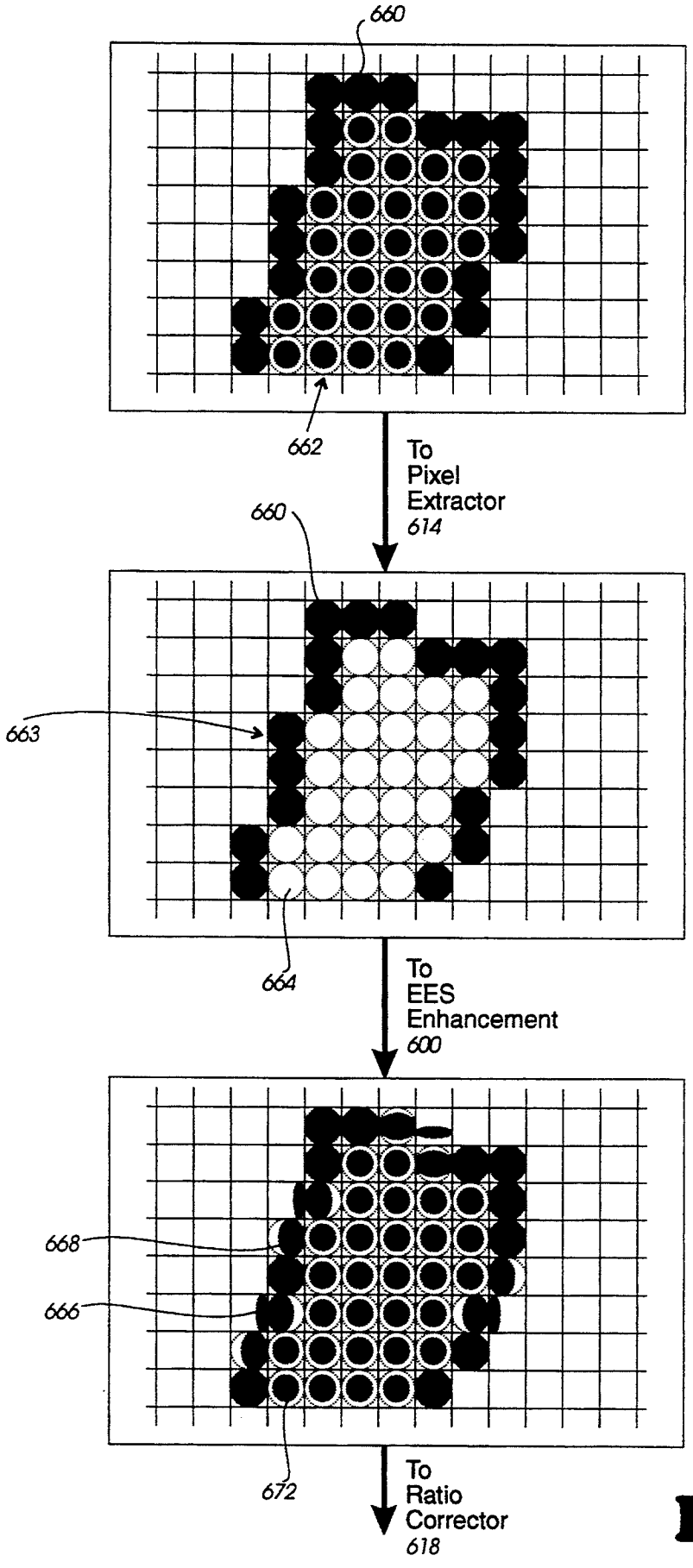

660
662
To
Pixel
Extractor
614
660
663
664
To
EES
Enhancement
600
668
666
672
To
Ratio
Corrector
618

FIG. 20

# MULTI-BIT IMAGE EDGE ENHANCEMENT METHOD AND APPARATUS

## BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates generally to apparatus and methods for controlling dot matrix output devices, such as cathode ray tubes and dot printing devices, e.g. laser printers and the like, to enhance edge representation when an image of an object is converted from graphical/mathematical format to display or print device format (a series of dots/pixels). More particularly, the present invention is directed to an improved implementation of weighted gradient work theory and associated logic used to provide image edge transition smoothing of both gray scale and text images in an efficient real time image enhancement system.

2. Brief Description of the Prior Art

In the field of image processing, research efforts have concentrated in the area of improving visual effects of object representation on output devices. Edges of original image objects, such as text, curves, boxes, and others, can be approximated by either linear or exponential equations. When these objects are digitized and converted into a matrix format which the output devices can accept, the integrity of the edges is usually compromised to fit the image objects into the device grids. The resulting staircase effects are quite visual to human perception in most of the commercially available products which have either low or medium resolutions.

The approximated appearance can be enhanced by locating the jagged edge segments and correcting the segment transition, or by increasing the device resolution to minimize the visual distortion to the degree that the naked eye can not differentiate the transition. However, increasing device resolution requires larger memory storage for the bitmap representation. The extra cost incurred by the memory is not desirable for general commercial products.

U.S. Pat. No. 4,321,610 issued to Moore et al. and entitled "Dot Matrix Printer with Half Space Dot Capability", discloses a technique which utilizes a half-dot character memory matrix and a shift register to enhance edges by coupling a half dot with an edge dot. This method at best enhances the resolution by a factor of two at the expense of extra memory storage and emboldening result.

U.S. Pat. No. 4,847,641 issued to Tung and entitled "Piece-wise Print Image Enhancement for Dot Matrix Printers" discloses a template matching method to correct error cells. Tung's invention utilizes the more recent pattern recognition and template matching process generally known in the image processing field; it is by far the most efficient way to enhance jagged line appearance. However, template matching and the compensation cell method limits its feasibility to use in monochrome devices only. While gray scale devices may share many similarities with monochrome devices, Tung's method would not be able to identify different gray patterns.

In a recent study of image segmentation and improvement, reported in the textbook entitled *Digital Image Processing* by Rafael C. Gonzalez and Paul Wintz (Addison-Wesley Publishing Company, 1977), weighted gradient mask matrices are applied to identify segments of an object by detecting changes in brightness. Due to the nature of complex matrix multiplication, this approach is recommended for remote usage for military or research purposes where computation power is sufficient and time is not a concern, but never in real time applications where segment recognition and modification need to be accomplished before the next pixel is displayed or printed.

As disclosed in U.S. Pat. No. 5,029,108 issued to James C.Y. Lung and entitled "Edge Enhancement Method and Apparatus for Dot Matrix Devices" it has been found that with selective entries in the gradient mask matrices, a simplified formula can be implemented to use the weighted gradient mask matrices to enhance the output of an electrophotographic printing machine or computer monitor display. This approach serves as an improvement over the prior art template matching methods which are not flexible in enhancing the gray scale applications. In order for the weighted gradient matrices to operate on gray scale objects, the entries of the matrices would range from 0 to 1 in any fractional increment manner, theoretically speaking. However, in real-time applications where limited computation power is a constraint, having fractional entries for gradient matrices requires complete matrix operations, such as multiplication, which extend beyond the usage of simple AND and INVERTER logic and therefore impose a restriction of the usage of the apparatus.

As outlined in the examples of the Lung patent, by confining the entries to two discrete values, 0 and 1, the disclosed method and apparatus can enhance edges along segment transitions with simplified logic to reduce the computation complexity. However, there continues to be a need for a similar apparatus and method which preserves the simple logic manipulation with modified weighted-gradient-matrix operations but further includes means for achieving gray scale edge enhancement.

## SUMMARY OF THE INVENTION

The present invention provides a technique for detecting the presence of edges in image data and then determining if the detected edge is part of a segment transition. Based on the finding, the edge data is modified either by repositioning related dots, or by altering the dot size so that a more accurate reproduction of the image can be generated by monochrome and gray scale devices.

In accordance with the present invention, video image data containing text, line art, or gray scale information is passed through a "pixel extractor" logic unit with a predetermined threshold value. The image data with a "brightness value" greater than or equal to the threshold value will be extracted out to be further examined for the presence of an edge transition. This pixel extractor unit serves as a filter for multi-bit video input data to be converted into a bi-level representation. The extracted bi-level image data are input to a temporary FIFO storage where a group of gradient mask matrices are applied to a "current matrix" wherein a TBAP (To Be Adjusted Pixel) is surrounded by 8 neighboring pixels, to determine if the TBAP is at a location where a change of brightness occurs. From this matrix operation, a conclusion is derived as to the existence or non-existence of an edge and the direction of the brightness change. The current matrix and a predetermined number of previously evaluated and yet to be evaluated pixels are then compared to a set of reference bit patterns which depict possible segment changes to be cor-

rected. If the result indicates that the TBAP is on an edge of a changing edge segment transition, a corresponding code will be generated to modify the TBAP to enhance the smoothness of a segment transition. The modified TBAP is encoded as a percentage to signify the change to be applied to the original multi-bit data. In accordance with the present invention, the modified TBAP is further corrected as a function of the signal level of the corresponding video image data. Thus, a modified TBAP with a 60% value for an original 50%-gray dot will result in a final 30%-gray dot, whereas the same 60% modified TBAP for an original monochrome black dot will result in a smaller dot size equivalent to 60% of a full dot. The modification of the size of monochrome dots and the gray shading of gray scale dots will create smoother edge segment transition and cause the edge to appear less jagged than the unaltered representation. Ultimately, this technique offers a visual effect equivalent to that provided by a higher resolution device without employing as much memory as would be required in the high resolution device.

This derived weighted gradient mask matrix uses AND and INVERTER logic for the matrix convolution process to eliminate CPU-intensive addition and multiplication calculation. By further including a pixel extractor device and associated ratio correction logic, the same efficient algorithm can be applied to monochrome and gray scale devices alike. Therefore, a system utilizing the present invention can achieve higher output quality in real time applications.

Furthermore, the present circuitry design provides for inclusion of a number of modulation registers for accommodating output-engine-specific, pulse-width/-dot-size relationship. The present circuitry can also support an external ROM (Read Only Memory) or PAL (Programmable Array Logic) device to store additional information for fine-tuning the adjustments to be made in individual output devices. This modulized design extends the flexibility of this present invention and offers a general solution to serve various devices, while it preserves the uniqueness of each dot-printing machine.

## IN THE DRAWING

FIG. **1***a* illustrates a typical change in brightness and its visual effect;

FIG. **1***b* illustrates the definition of an "edge" as a point in space where its value of brightness differs from its neighboring point;

FIG. **2***a* is a diagram illustrating a prior art bitmap representation of an area after a "grid fitting" process. The round darker dots represent pixels that are turned "ON" whereas the lighter shaded area illustrates the brightness change as perceived by the human eye;

FIG. **2***b* is a diagram illustrating the bitmap representation of FIG. **2***a* after edge enhancement in accordance with the present invention. Dots ranging from 50%-80% which were turned "ON" as full dots in FIG. **2***a*, are now adjusted to enhance the smoother representation of the edge. The 30% dot, which in FIG. **2***a* was not an "ON" pixel, is now adjusted to enhance the edge;

FIG. **3***a* outlines 4 possible slopes of defined "segments" in digital applications;

FIG. **3***b* illustrates an example of an object composed of a plurality of edge segments **1–10**;

FIG. **4***a* is a diagram showing the mathematical definition of a "vertical edge segment" as used in the present invention;

FIG. **4***b* shows an example of an unmodified step transition if a vertical edge segment and a corresponding edge-enhanced vertical segment;

FIGS. **5***a* and **5***b* are diagrams illustrating "horizontal segments" as contrasted with the vertical examples depicted in FIGS. **4***a* and **4***b;*

FIG. **6** illustrates how laser beam pulse manipulation can yield various results in a single pixel;

FIG. **7***a* illustrates the Gradient Mask convolution concept and the general formula applied in gradient mask matrix operation;

FIG. **7***b* illustrates the simplified, derived format of the weighted gradient mask, and the rules used in the present invention for edge detection;

FIGS. **8***a* and **8***b* are examples of how the rules and formula are applied, and the results of derivation;

FIG. **9***a* is a block diagram illustrating the major building blocks of a laser printer controller;

FIG. **9***b* is a block diagram illustrating the data flow within a predecessor edge enhancement apparatus;

FIG. **10** is a logic flow chart depicting the segment detection and decision making process of the apparatus depicted in FIG. **9***b;*

FIG. **11** shows an example of segment detection by examining the past and future trend of the current edge;

FIG. **12** is a chip design block diagram of the FIG. **9***b* apparatus showing the relationship of edge enhancement circuitry and signals;

FIG. **13** is a block diagram depicting the pulse width modulation components of a modulation subsystem of the FIG. **12** apparatus;

FIGS. **14** and **15** illustrate an example of how the FIG. **12** apparatus preserves the unique property of an individual electrophotographic printing machine under the general formula;

FIG. **16** is a block diagram illustrating the data flow;

FIG. **17** is a logic flow chart of the pixel extractor;

FIG. **18** depicts an example of how a 4-bit input gets converted to a bi-level format;

FIGS. **19***a*–**19***b* illustrate an example of data conversion along an ideal edge of a gray scale image, the size variations representing gray levels if the examples were to be printed by gray scale-capable devices; and

FIG. **20** illustrates a conceptual flow of the pixel extractor unit identifying edge segments and the eventual edge-enhanced result.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention can be applied to various dot matrix devices, such as cathode ray tubes, electrophotographic printing machines, etc., to enhance the edge smoothness of the images generated or reproduced thereby. The particular apparatus described herein is an application specific integrated circuit (ASIC) for laser printers, realized by implementing the present invention. However, it is understood that the invention can be adapted for use in other dot matrix devices to enhance edge appearance using the same technique.

Dot matrix devices produce output in bitmap formats to be displayed on a CRT or printed on paper or other hard media. In the process of digitizing data into bit maps, a certain degree of loss in precision is inevitable. Furthermore, after the "grid fitting" process of putting the digitized data into the device framework, further data loss is introduced. Therefore, visible distortion in the final representation is normally found across the spectrum of the various types of low to medium resolu-

tion devices. Typically, the distortion is most obvious near edge transitions, where brightness changes from one level to the other.

Predecessor Edge Enhancement Technology (EET)

The method and apparatus disclosed in U.S. Pat. No. 5,029,108 teaches implementation of an edge enhancement algorithm which locates edge segment transitions and changes in brightness, and sharpens the edge representation in various subdot combinations. Since the EET apparatus, sometimes referred to as an Edge Enhancement Sensor (EES), forms a part of the present invention, the disclosure of the above-identified patent is repeated herein and includes the depictions of FIGS. **1–15**.

The human eye is usually more sensitive to changes in color, shades, depths, than to a continuous area wherein no variation is present. FIG. **1***a* shows one example of an area including transitions between seven different shades. Looking briefly at this image, one will note that the eyes pay more attention to the edges where shades change than to any difference in shade. In FIG. **1***b*, a small square area **100** of a changing edge is enlarged to illustrate the edge **101** demarking a transition from a 30% gray level region **102** to a 50% gray level region **104**. The small squares represent the device grids (pixels) with the ideal edge **101** passed through. An objective of the present invention is to adjust the final output, with all device limitations taken into consideration, so the near ideal edges are reproduced.

In a digitizing and grid fitting process as illustrated at **114**, a dark object with a left edge inclined at an angle near 45° will be placed in the device frame to be displayed or printed, as shown in FIG. **2***a*. The actual, or ideal, edge **112** of this object is distorted in the process of bitmap conversion. More specifically, a pixel that has 50% or more of its area covered by the dark object is determined to be an "ON" bit, as depicted at **110** for example. However, a pixel having less than 50% of its area covered by the object is identified as an "OFF" bit, as depicted at **111**. Thus, a printout or display of this representation forms a jagged edge rather than the straight edge **112**. The lighter shaded area **116** in FIG. **2***a* represents the resulting shape of the object as perceived by the human eye. The EET apparatus enhances the edge representation so that it appears substantially less jagged as depicted in FIG. **2***b*.

In the EET apparatus, the jagged edge in FIG. **2***a* is adjusted by the insertion or substitution of various smaller dot sizes **122** to smooth the edge. The dotted lines **120** in FIG. **2***b* indicate where a full dot in FIG. **2***a* is now shrunk to a smaller size dot **122**, and a 30% dot **124** is added to pad the area which normally would not have been an ON pixel. As illustrated at **126**, the adjustable dot size of the present invention can vary from $\frac{1}{2}$ to 1/32 of a full dot. By varying the dot size to enhance edges, as indicated at **128**, a smoother edge representation can be achieved.

An edge segment is defined as a series of adjacent, aligned dots which collectively define a line having the same slope. There are four kinds of segments in a digital system: 90°, 0°, −45°, and 45°, as depicted in FIG. **3***a* Any other slopes can not be represented perfectly in digital format without staircase distortion. The example illustrated in FIG. **3***b*, shows a contour which is composed of **10** segments **1–10**.

In FIG. **4***a*, two types of transitions between segments are illustrated. Each type includes two vertically disposed but laterally displaced segments. Pixel dots $P_{x,}$ $_{y+1}$ **130** and $P_{x,y}$ **132** of FIG. **4***a* belong to the same 90° segment. Pixel dots $P_{x+1,\ y-1}$ **134** and $P_{x+1,\ y-2}$ **136** are likewise two pixels of a 5 dot segment. $P_{x,\ y}$ **132** and $P_{x+1,\ y-1}$ **134** form a segment change.

In a dot matrix device, all edges can be broken down into segments. One segment can comprise any number of dots. In FIG. **4***a* type #**1** is a near straight vertical line. The mathematical **4** model to represent the line is:

$$VL1\ (N,M)_{x,y} = \sum_{n=N}^{1} P_{x+1,y-n} + \sum_{m=0}^{M} P_{x,y+m}$$

In FIG. **4***a* type #**2** represents the other possible vertical segment transition, which can be expressed as:

$$VL2\ (N,M)_{x,y} = \sum_{n=N}^{1} P_{x-1,y-n} + \sum_{m=0}^{M} P_{x,y+m}$$

Since a segment can be composed of any arbitrary number of dots, the following equation can be used to include all type **1** jagged vertical lines:

$$V1=\Sigma\Sigma\ VL1(N,M)$$

And the summation of all type **2** can be expressed by:

$$V2=\Sigma\Sigma\ VL2(N,M)$$

The equations for horizontal cases (FIG. **5***a*) are:

$$HL1\ (N,M)_{x,y} = \sum_{n=M}^{0} P_{x-n,y} + \sum_{m=1}^{M} P_{x+m,y+1}$$

$$HL2\ (N,M)_{x,y} = \sum_{n=M}^{0} P_{x-n,y} + \sum_{m=1}^{M} P_{x+m,y+1}$$

Similarly, the summation of all the type **1** and type **2** jagged horizontal lines can be expressed as:

$$H1=\Sigma\Sigma\ HL1(N,M)$$

$$H2=\Sigma\Sigma\ HL2(N,M)$$

The allowed input values for N and M determine the pixel input capacity of sampling circuit. In order to use the present invention in a real time application, N and M can not be too large.

To show how the equations work with the segment concept, FIG. **3***b* will be used as a reference. Let the notion of SEG(m-n) indicate the transition from an arbitrary segment #m to segment #n. The jagged SEG(**5–6**), SEG(**7–8**), and SEG(**8–9**) of FIG. **3***b* must be smoothed, while SEG(**1–2**), SEG(**4–5**) and SEG(-**6–7**) are left alone. However, SEG(**2–3**), SEG(**3–4**), SEG(**9–10**), and SEG(**10-1**) are optional to the implementation. The above equations can be applied to detect these segment changes with some appropriate N and M values.

An Edge Enhancement Sensor (EES), to be further described below, is implemented to locate and improve edges. Within the EES structure, a Segment Change Detector (SCD) is used to determine if there is any change about a current pixel by tracing the history and the future of each segment. The above equations are

embedded in the Segment Change Detector system to evaluate the edge condition.

Once a segment change is detected and this change is determined to be an effective change, such as SEG(5–6) in FIG. 3*b*, then an appropriate modulation signal will be generated to modify the TBAP by changing its width, height, or both. In FIG. 4*b*, the TBAP **140** is on the edge of a changing segment. It is thus replaced by three $\frac{1}{4}$ subdots **141** and coupled with another $\frac{1}{4}$ subdot **142** for its adjacent pixel. Therefore, to the human eye, a full size dot appears to be shifted to the right a distance equal to $\frac{1}{4}$ of a regular pixel width. Similarly, when the next line is evaluated and pixel dot **143** becomes the TBAP, it is replaced by two $\frac{1}{4}$ width subdots **144** and two additional $\frac{1}{4}$ width subdots **145** are added to the adjacent pixel. This gradual movement of dots and subdots thus provides the intended edge enhancement.

FIGS. 5*a* and 5*b* illustrate the horizontal example of segment detection and edge enhancement. In FIG. 5*b*, the TBAP **160** is modified to provide a 75% dot visual effect with one full pixel width and smaller height. Whereas pulse width modulation can be used to modify the width of a pixel dot, as illustrated at **167** in FIG. **6**, to achieve a flatter dot in a laser printer, two signal pulses **166** which in combination give the desired energy level are used in the place of one pixel signal. For example, in FIG. **6** two smaller dots **164** overlapping each other create the illusion of a single flat dot **165**. Due to the characteristics of the laser printer drum mechanism, the two narrow pulses **166** not only shrink the width of each dot **164** but also the height thereof. However, if the energy level peaks through the threshold, a shorter than full width pulse **169** still yields the full height dot **168**.

All prior art resolution enhancement or edge improvement systems use similar architecture approaches: first they locate the trouble area, then they improve the situation. In the EES, the equations mentioned above serve to define segments while weighted gradient masks determine the directions of changes.

A Gradient Mask is an "a×b" matrix wherein a and b are integers and particular weights are given to a pre-determined matrix of bit cells, so that a particular type of gradient change can be identified. Gradient changes introduce edges. Thus the EES is used to enhance edges.

The mathematical way to apply a weighted gradient mask **174** (FIG. 7*a*) to a particular matrix or bitmap pattern **172** is not the standard matrix operation. Instead, the two matrices are convolved by a convolution operator as described in FIG. 7*a*. Specifically, the value of each cell in the first matrix is multiplied by the value of the cell in the same location of the second matrix. The sum of the multiplications then yields a value which can be used to determine the direction of the gradient. The entries for each cell of the subject matrix can be numbers that represent different colors, intensities, or gray shades. The entries for the cells of the gradient masks are numbers which carry different weights to distinguish various gradients.

An ASIC (application specific integrated circuit) for laser printers, only needs to handle black and white. Since black and white are two discrete levels and there is nothing inbetween, 1 and 0 are respectively used to represent a black, or "ON" pixel and a white, or "OFF" pixel Rather than using complex multiplication, a new weighted gradient mask operation is derived to use boolean operations as illustrated in FIG. 7*b*. Thus the calculations are narrowed down to just boolean AND and NOT operations as expressed at **188** to extract the gradient features that used to be used in the standard convolution methodology. The circuitry is also simplified. The result is that the method can now be implemented in real time applications which were previously considered inapplicable in prior art systems.

The detailed flow is carried through by using the example in FIG. 8*a*: Suppose segment condition of the current pattern **172** (a 3×3 pixel matrix) to be determined is convolved with a particular gradient mask **174** which is configured to detect an East Segment (E-Seg), ie., a segment transitioning from dark to light in the East or right side direction. Each pre-determined gradient mask has an ideal number associated with it which indicates detection of a segment having a corresponding condition. If the associated ideal number results from the application of a particular gradient mask, then the particular condition **194** is identified, that is, the direction of the gradient change of a current pattern is detected. Since each gradient mask has at least some Os to offset certain insignificant cells **202**, the notation "X" is used. These "X" cells can have either 0 or 1 values, which will make no difference in the outcome, because the Os in the gradient mask would not offer any weight to them. In order to determine if the Os and Is form the tested for gradient, a "−1" notation is introduced (as shown at **200**) as a NOT in the boolean expression. Any cell in the current pattern matrix which is operated upon by the "−1" will be inverted. Thus, only Os in the current pattern matrix will contribute weight when operated upon by "−1"s. Should the resulting weight be less than the ideal number associated with the particular gradient mask, then no match will be found and the current pattern will be tested against another in the set of pre-determined gradient masks stored in the apparatus. FIGS. 8*a* and 8*b* show only a subset of those gradient masks used in the apparatus to detect the horizontal and vertical transitions. It is to be understood however that in accordance with the present invention a complete set of predetermined gradient masks can be executed concurrently.

FIG. 9*a* is a simplified block diagram outlining the principal functional components of a laser printer and its controller **281**. As is well understood in the art, after the laser printer interpreter **282** has parsed and processed the symbolic page objects, the physical page is converted into bitmap format and temporarily stored in the frame buffer **300**. The frame buffer **30**, as is more clearly shown in FIG. 9*b*, shifts out the bits to Edge Enhancement Sensor (EES) **316** so that they can be monitored for edge enhancement. The incoming bit stream is stored in a temporary storage, a first-in-first-out (FIFO) memory buffer **302** (FIG. 9*b*). Within this buffer, a predetermined bit location is assigned as the TBAP (to-be-adjusted-pixel). This TBAP is in the center of a 3×3 pattern matrix which will be convolved in a gradient mask edge detector **304** with a set of gradient mask matrices to detect the existence of an edge segment. The result of the convolution also indicates the direction of gradient change, and based on the direction given, the bit pattern matrix is classified as either a horizontal or vertical pattern. A horizontal pattern is one which includes a horizontal edge segment. A vertical pattern is one which includes a vertical edge segment. Horizontal and vertical groups are also defined. A horizontal group includes a horizontal pattern, a predetermined number of previously evaluated bits

(pixels) (**366** in FIG. **11**) and a predetermined number of yet to be evaluated bits (pixels) (**367** in FIG. **11**). Horizontal and vertical sets of reference bit patterns, each pattern of which includes a pattern of bits corresponding to one possible combination of bits aligned in one or more segments, are also provided for. Once the pattern matrix is determined to be either vertical or horizontal and its corresponding group is identified, the HLINE or VLINE **408** (FIG. **12**) is activated accordingly, and a comparison is made by either vertical detector **428** or horizontal detector **430**. All reference bit patterns in a particular group are simultaneously compared bit by bit to the bits of the group including the present pattern matrix, the previously evaluated bits **366** and the yet to be evaluated bits **367**. The comparison will decide if the TBAP needs to be modified. If a modification is required for this TBAP, the address generator **308** (FIG. **9***b*) generates an address code identifying where the associated modulation instruction resides. The modulation instruction is then processed by the modulation logic **312** to alter the original signal and output a modulated video signal **314**. If there is no match found during the group comparison operation, then there is no modulation required. FIG. **10** shows the logical decision making process.

Most laser printers are similar in their mechanism and functions, although the relationship of laser beam mechanism and drum varies somewhat from different engine models and manufacturers. The EES offers the flexibility of supporting multiple output devices and their unique pulse-width/dot size relations by allowing an external ROM or PAL device to be included in Look Up Table **310**. This external ROM/PAL device can store more modulation instructions than the existing apparatus to give some laser driving engines further precision control, while still keeping the cost low for most engines having near standard characteristics.

To synchronize the process so that all edge enhancement steps for one TBAP can be accomplished in real time before the next pixel arrives, the present apparatus outlined in FIG. **12** accepts on input **400** the /BD (beam detector) signal from the engine, as well as the /VDOCLK (video clock) input on line **414**. Since the same clock source is needed to synchronize the printer controller functions, /HSYNC (horizontal sync. signal) input at **402** and DOTCLK input at **404** are passed to the printer controller **281** (FIG. **9***a*). The VDOCLK signal **414** has R times higher frequency than DOTCLK **404** which is used by the printer controller, the /VDOCLK **414** is thus divided by R in divider **422** to give the DOTCLK signal the correct frequency. The value of R is a variable which will be used to divide a full size dot by 2R. For example, if R=5, then one full size dot can be divided into 10 subdots for various combinations. The practical integers for dividers for this kind of application are from 1 to 16, which will yield subdot size from $\frac{1}{2}$ to 1/32. However, the bigger the divider, the higher the resolution and video frequency.

The video image data VDOIN signal **406** is passed from the printer controller and stored temporarily in the FIFO **302**. The current pattern matrix with the TBAP is then convolved at **304** with the gradient masks to effect edge detection and is then compared with either the vertical group or horizontal group of data in detectors **428** and **430**, respectively. There is a predefined lookup table **432** built into the apparatus for the appropriate modulation code associated with the current condition. Furthermore, as mentioned earlier, an external lookup device (addressed via line **410**) can be attached for more flexibility. The instruction code of the desired modulation from either the default lookup table **432** or the external lookup (input on line **412**) table is then input to the modulator subsystem **312**.

Referring now to FIG. **13**, the modulator **312** receives at least one input, or perhaps two if an external lookup table ROM/PAL is installed, which are input to the multiplexer **504** to generate a resulting code for input to modulation registers **506**. The modulation registers **506** are programmable registers which can be initialized by the printer controller at power-on time. The data stored in these registers are implementation dependent. For example, as shown in FIG. **14**, two sample registers can have different signal combinations **550–556** stored therein. This example illustrates the case wherein one dot is divided into 16 subdots by setting R in the divider **422** (FIG. **12**) to 8. Each modulation register in **506** (FIG. **13**) is indexed by the instruction input thereto from the multiplexer **504** and an associated address code which points to the desired signal location to use (see FIG. **15**). The desired signal will replace the original TBAP signal in the modulation logic **508** and send out the final modified video signal (VDOOUT) on line **314**.

Since the EES utilizes a simplified weighted gradient mask matrix operation, the entries of matrices are limited to either 0 or 1. As indicated above, the benefit of this binary approach is that the computation scope can be narrowed down to two logic operators—AND and NOT (an inverter in circuitry building); however, the inherited disadvantage of the EET method is that only 1-bit monochrome image data can be processed and enhanced.

The Improved Edge Enhancement Method and Apparatus

The present invention improves upon the EET apparatus allowing it to accept multi-bit data structures so that gray scale images as well as monochrome objects can both be caused to have smoother edges as they are printed or otherwise depicted.

Turning now to FIG. **16**, a block diagram illustrating the present invention is depicted. At the outset it will be noted that the EET component **600** in the diagram of FIG. **16** includes the principal functional components of the EET apparatus depicted in FIG. **9***b*. More specifically, it includes a FIFO **602**, an Edge Enhancement Sensor (EES) **604** with Edge Detector **606** and Segment Change Detector **608**, an Address Generator **610**, and a Lookup Table **612**. These components function as described and depicted above in FIG. **9***b* and subsequent figures and develop an enhanced data signal (modification signal) at **622** which is either of a first state (**1**) or a second state (**0**). If the signal is of the first state, its duration may be a fractional part of the pixel data period. In accordance with the present invention, pixel extractor **614** is added between the input signal bus **616** and the input to FIFO **602**, and serves to convert each multibit (M-bits) video input signal input on bus **616** to a two level (bi-state) signal, the data state of which is determined by its relation to a predetermined threshold signal level. This is to say that if the value of the M-bit signal is equal to or exceeds the threshold, a "1" is output, otherwise a "0" is output. This enables the EET Component **600** to function in the manner previously described.

A Ratio Corrector **618** responds to a corresponding multibit video signal stored in latch **620** and operates to

modify the enhanced data signal developed at **622** such that its duration is reduced in proportion to the gray scale value of the corresponding M-bit signal, and the resulting compensated signal is used to drive a Pulse Generator **624**, the output of which is coupled into one input of a Multiplexer **626**. The compensated signal appearing at **623** is also input to a first input of a second multiplexer **628**.

As indicated, the M-bit video input at bus **616** is also input to a second input **630** of multiplexer **628** and into a "gray palette" lookup table **632** which converts the M-bit signal into a binary signal, the duration of which is a fraction of the pixel signal period proportional to the gray scale value of the M-bit signal. The output of gray palette **632** is thus in the same form as the output of pulse generator **624** and is suitable for driving a marking engine such as that used to drive a laser beam printer. The multiplexers **626** and **628** respond to signal comparitors **634** and **636** respectively and serve to select one of the two inputs to MUX device **626** for input to the marking engine, and in the case of multiplexer **628** to a gray scale engine of the type used in high end type-setting machines and the like. In accordance with the present invention, the comparators generate control signals which cause their corresponding MUXs to select the compensated signal for input to their engine if the compensated signal is HI for any part of its pixel period, and to select its alternate input if the compensated signal is LO for the entire pixel period.

The logical operation of pixel extractor **614** is depicted in FIG. **17** and, as suggested above, serves to determine whether or not the multibit video input is greater than or equal to a preselected threshold level. If the level is not greater than or equal to the threshold level, then the pixel signal is set to a "0" level and stored in the FIFO **602**. If, on the other hand, the video input is greater than or equal to the threshold level, then the pixel signal is set to a "1" and input to FIFO **602**. This operation is continued for each multibit video input signal identifying a single pixel of the serially input data.

The operation can alternatively be depicted as represented in FIG. **18** wherein a four bit hex format video input data stream is shown input to the pixel extractor represented by box **614** where it is compared to a threshold point **615** and the extracted binary output signal is generated at **617**.

To contrast operation of the present invention with that of the above identified Lung patent, reference is made to FIGS. **19***a* and **19***b*, and to FIGS. **2***a* and **2***b*. Note that whereas in FIG. **2***a* all data is characterized as being either black or white, in FIG. **19***a* the data is depicted by dots of various sizes representing the corresponding gray scale data content of each pixel. As in the prior Lung system, in order to improve the jagged edge of the depicted image and make it better conform to an ideal edge (**112** in FIG. **2***a* and **640** in FIG. **19***a*), the sizes of various dots are modified and/or additional dots are added to pixel locations not initially containing such dots. The difference, however, is that whereas the modified dots depicted in FIG. **2***b* are in the form of percentages of full dot size, the dots developed in accordance with the present invention and depicted in FIG. **19***b* are in the form of percentages of gray scale dot size.

More specifically, in accordance with the present invention, the jagged edge generated from the digitizing and grid fitting process and reflected in FIG. **19***a* are compensated by altering the gray level of dots **642** and **644** which appear along the ideal line **640**, and/or by adding extra gray dots to pixel sites **646** and **648** to simulate a smoother edge representation. Such alterations are depicted in FIG. **19***b* at **643** and **645**, and at **647** and **649**.

The maximum dot size (**650**) fitted in the pixel grids **652** characterizes a 100% gray level (i.e. a black dot) whereas a smaller shaded dot **654** bounded by a dotted full size dot circle **656** characterizes a percentage of max gray. The value of a specific gray level is judged by the ratio of the shaded area to the full dot size. To avoid a sudden brightness change which is unpleasant to the human eye, the altered enhancement dot **649** is calculated as a fraction of its neighboring dot **651** which, according to the EET method disclosed in the Lung patent, is designated a TBAP. The illustrated process offers a subtle compensation to increase the edge sharpness without interfering with the original image data.

In operation, referring to FIG. **20**, the dots **660** which form the edge of an object **662**, regardless of whether it is a simple black and white character or a multibit gray scale image, are extracted by the pixel extractor **614** (FIG. **16**), and depending on their size relationship to the selected threshold, are converted to binary states to develop a binary edge segment format as illustrated at **663**. A binary representation in the present invention is defined as either having a positive response value or having a value below the threshold value. In the illustrated example, the threshold value is said to be set at 100% gray (black) to extract only black edge segments and to ignore all other gray levels. As a consequence, the output of the pixel extractor **614**, to be loaded into FIFO **602**, would, as indicated at **663**, consist of a collection of black pixels **660** surrounding a plurality of white pixels **664**. By applying this input to the EET components **600**, the edge segment transitions will be smoothed by repositioning dot locations, as indicated at **266**, and by modifying dot sizes, as indicated at **668**. After smoothing the edge segments, the interior dots filtered out by the threshold setting in extractor **614** are set back to their gray levels as indicated at **672**. The pixel extractor **614** allows a programmable threshold to be selected for fine tuning of the operation.

Stated alternatively, as illustrated in FIG. **17**, the multibit input data stream passes through the threshold subsystem to be separated into two groups. The pixels with gray level greater than or equal to the selected threshold are assigned a value "1" while the pixels with gray level less than the threshold value are set to "0". The two types of pixels, namely ON and OFF dots, are stored in the FIFO **602** to be examined by the edge enhancement sensor (EES) of the EET unit **600** as described in the above referenced Lung patent.

An alternative illustration depicted in FIG. **18** shows a four bit data stream **670** in hex format being fed into a threshold subsystem **614** having a preset threshold value as indicated at **615**. The resulting output at **617** is a bilevel representation of the multibit input format.

More specifically, the EES **604** (FIG. **16**) receives data from FIFO **602** in a sequential manner and invokes first edge detector **606** and then segment change detector **608** to examine whether the TBAP (To Be Adjusted Pixel) needs any modification to smooth the edge transition. Should an adjustment of a TBAP be necessary, the EES subsystem **604** will cause the address generator **610** to develop an address code for input to the lookup table **612** where the predefined appropriate modulation code associated with the current condition is stored. A detailed execution process for FIFO **602**, Edge Detector

606, Segment Change Detector 608, Address Generator 610, and Lookup Table 612 is disclosed above with regard to the description of FIGS. 9*b* et seq. However, in this embodiment, the data format of the modulation code output by lookup table 612 is an M-bit code where M is the number of bits of the input data format. The M-bit modulation output code from lookup table 612 is passed to the ratio corrector unit 618 which responds to the original dot information contained in latch 620 to modify the output code. Since the current M-bit code has a specific gray value (e.g. 1000 in a four bit format=8/16=50%), by combining the original dot size (N%) with the current modulation ratio (M%) the ratio corrector unit 618 can generate a desired compensation value at node 623 to smooth the current segment transition.

The pulse generator 624 reads in the correction value and generates a corresponding pulse signal at 625. For a laser marking engine to obtain the other group of input data which falls below the threshold point, the original multibit video input signal is converted into various dot sizes to simulate the gray palette 632. Thus, a 4-bit value, such as 1000, is converted to map into a 50% monochrome dot size. By joining different dot pulses generated from the Gray Palette with the output from the pulse generator 624, using the multiplexer 626, a laser marking engine driven by the combined signals can simulate print quality close to that of a true gray scale device with the edge transitions smoothed. If the target output device is not a laser marking engine but is instead a true variable-dot-size gray scale print device which accepts multi-bit data input, the M-bit correction value at node 623 and the original multibit video input are sent into the multiplexer 628 to generate the combined and modified image video data with certain edges enhanced.

Although the present invention has been described above in terms of an apparatus for enhancing the output of a laser printer or a gray scale engine, it will be understood by those skilled in the art that the present invention can likewise be implemented to control the intensity of the cathode ray beam, or beams, in a video display device or similar apparatus. It is therefore intended that the appended claims be interpreted to cover all alterations, modification and applications that fall within the true spirit and scope of the invention.

What is claimed

1. A method for enhancing the displayed image of a print or display apparatus, comprising the steps of:

generating a set of gradient masks each of which represents a plurality of edge segment transition conditions and includes a matrix of "a×b" cells, each cell of which is assigned a numerical weight corresponding to the relative lightness or darkness of the corresponding pixel of an image having an edge segment passing through a center pixel of the matrix;

generating a data signal including a plurality of multi-bit data terms representative on a pixel-by-pixel basis of a bit map image to be printed or displayed;

evaluating each said multi-bit data term, and if the value thereof is equal to or greater than a predetermined threshold value, then generating a data bit of a first state, if the value is less than said threshold value, then generating a data bit of a second state;

storing in temporary storage means a predetermined number of consecutive data bits in a predetermined number of consecutive lines of said bit map image;

selecting subsets of said data bits forming a sample matrix of "a×b" data bits, the central bit of each sample matrix being a candidate for modification;

convolving each said sample matrix with each said gradient mask to detect those sample matrices having an edge segment passing through their central data bit, said edge segment being defined as a series of adjacent aligned data bits of the same data state forming a straight line having a single slope, and to determine the direction of a gradient change;

generating a set of reference bit patterns each of which includes a subpattern of bits corresponding to one possible combination of data bits of the same data state aligned in one or more edge segments, said pattern including an "a×b" matrix of data bits, a first predetermined number of data bits disposed adjacent one side of said matrix, and a second predetermined number of data bits disposed adjacent another side of said matrix;

comparing each said sample matrix having an edge segment passing through its central data bit, a predetermined number of adjacent previously evaluated data bits, and a predetermined number of adjacent yet to be evaluated data bits to each pattern of at least a sub-set of said set of reference bit patterns;

generating for each match found to a reference bit pattern including a predetermined type of segment transition, a modification signal for modifying the central data bit of said sample matrix dependent upon the type of transition detected;

combining each said modification signal with its corresponding multi-bit data term to generate a compensated value signal;

using each said compensated value signal to generate a compensated signal pulse which during at least a portion of its period is of a first data state, or is of a second data state for the duration of its period;

using each said multi-bit data term to develop a corresponding percent gray signal; and

using each said compensated signal pulse of said first state to cause a print or display apparatus to develop a corresponding output, but if said compensated value signal is of said second state, then using the corresponding percent gray signal to cause the print or display apparatus to develop a corresponding output.

2. A method for enhancing the displayed image of a print or display apparatus as recited in claim 1 wherein the convolving of each said sample matrix with each said gradient mask is accomplished using boolean algebra.

3. A method for enhancing the displayed image of a print or display apparatus as recited in claim 2 wherein a is equal to 3 and b is equal to 3.

4. A method for enhancing the displayed image of a print or display apparatus as recited in claim 2 wherein during said convolution step all said gradient masks are simultaneously convolved with the sample matrix.

5. A method for enhancing the displayed image of a print or display apparatus as recited in claim 2 wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

6. A method for enhancing the displayed image of a display apparatus as recited in claim 2 wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more

subdots having special characteristics different from the dot replaced.

7. A method for enhancing the displayed image of a print or display apparatus as recited in claim 1 wherein a is equal to 3 and b is equal to 3.

8. A method for enhancing the displayed image of a print or display apparatus as recited in claim 1 wherein during said convolution step all said gradient masks are simultaneously convolved with the sample matrix.

9. A method for enhancing the displayed image of a print or display apparatus as recited in claim 8 wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

10. A method for enhancing the displayed image of a display apparatus as recited in claim 8 wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

11. A method for enhancing the displayed image of a print or display apparatus as recited in claim 1 wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

12. A method for enhancing the displayed image of a display apparatus as recited in claim 11 wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

13. A method for enhancing the displayed image of a print or display apparatus as recited in claim 12 wherein said subdots change the apparent width and/or height of the dot replaced.

14. A method for enhancing the displayed image of a display apparatus as recited in claim 1 wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

15. A method for enhancing the displayed image of a print or display apparatus as recited in claim 14 wherein said subdots change the apparent width and/or height of the dot replaced.

16. A method for enhancing the displayed image of a gray scale print or display apparatus, comprising the steps of:

generating a set of gradient masks each of which represents a plurality of edge segment transition conditions and includes a matrix of "a×b" cells, each cell of which is assigned a numerical weight corresponding to the relative lightness or darkness of the corresponding pixel of an image having an edge segment passing through a center pixel of the matrix;

generating a data signal including a plurality of multi-bit data terms representative on a pixel-by-pixel basis of a bit map image to be printed or displayed;

evaluating each said multi-bit data term, and if the value thereof is equal to or greater than a predetermined threshold value, then generating a data bit of a first state, if the value is less than said threshold value, then generating a data bit of a second state;

storing in temporary storage means a predetermined number of consecutive data bits in a predetermined number of consecutive lines of said bit map image;

selecting subsets of said data bits forming a sample matrix of "a×b" data bits, the central bit of each sample matrix being a candidate for modification;

convolving each said sample matrix with each said gradient mask to detect those sample matrices having an edge segment passing through their central data bit, said edge segment being defined as a series of adjacent aligned data bits of the same data state forming a straight line having a single slope, and to determine the direction of a gradient change;

generating a set of reference bit patterns each of which includes a subpattern of bits corresponding to one possible combination of data bits of the same data state aligned in one or more edge segments, said pattern including an "a×b" matrix of data bits, a first predetermined number of data bits disposed adjacent one side of said matrix, and a second predetermined number of data bits disposed adjacent another side of said matrix;

comparing each said sample matrix having an edge segment passing through its central data bit, a predetermined number of adjacent previously evaluated data bits, and a predetermined number of adjacent yet to be evaluated data bits to each pattern of at least a sub-set of said set of reference bit patterns;

generating for each match found to a reference bit pattern including a predetermined type of segment transition, a modification signal for modifying the central data bit of said sample matrix dependent upon the type of transition detected;

combining each said modification signal with its corresponding multi-bit data term to generate a compensated value signal;

using each said compensated signal pulse to cause a gray scale print or display apparatus to develop a corresponding output, but in the absence of a compensated value signal, using the multi-bit data term to cause the gray scale print or display apparatus to develop a corresponding output.

17. A method for enhancing the displayed image of a print or display apparatus as recited in claim 16 wherein the convolving of each said sample matrix with each said gradient mask is accomplished using boolean algebra.

18. A method for enhancing the displayed image of a print or display apparatus as recited in claim 17 wherein a is equal to 3 and b is equal to 3.

19. A method for enhancing the displayed image of a print or display apparatus as recited in claim 17 wherein during said convolution step all said gradient masks are simultaneously convolved with the sample matrix.

20. A method for enhancing the displayed image of a print or display apparatus as recited in claim 17 wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

21. A method for enhancing the displayed image of a display apparatus as recited in claim 17 wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

22. A method for enhancing the displayed image of a print or display apparatus as recited in claim **16** wherein a is equal to 3 and b is equal to 3.

23. A method for enhancing the displayed image of a print or display apparatus as recited in claim **16** wherein during said convolution step all said gradient masks are simultaneously convolved with the sample matrix.

24. A method for enhancing the displayed image of a print or display apparatus as recited in claim **23** wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

25. A method for enhancing the displayed image of a display apparatus as recited in claim **23** wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

26. A method for enhancing the displayed image of a print or display apparatus as recited in claim **16** wherein during said comparison step a subset of said reference bit patterns is simultaneously compared to said sample matrix and its said previously and yet to be evaluated adjacent bits.

27. A method for enhancing the displayed image of a display apparatus as recited in claim **26** wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

28. A method for enhancing the displayed image of a print or display apparatus as recited in claim **27** wherein said subdots change the apparent width and/or height of the dot replaced.

29. A method for enhancing the displayed image of a display apparatus as recited in claim **16** wherein said compensated signal pulse causes the dot normally representing the central bit to be replaced by one or more subdots having special characteristics different from the dot replaced.

30. A method for enhancing the displayed image of a print or display apparatus as recited in claim **29** wherein said subdots change the apparent width and/or height of the dot replaced.

31. Apparatus for enhancing the output of a print or display device which produces an image in dot matrix format, comprising:

means for generating a set of gradient masks each of which represents a plurality of edge segment transition conditions and includes a matrix of "a×b" cells each cell of which is assigned a numerical weight corresponding to the relative lightness or darkness of the corresponding pixel of an image having an edge segment passing through a center pixel of the matrix;

means for generating a data signal including a plurality of multi-bit data terms representative on a pixel by pixel basis of a bit map image to be printed or displayed;

means for evaluating each said multi-bit data term, and if the value thereof is equal to or greater than a predetermined threshold value, then generating a data bit of a first state, if the value is less than said threshold value, then generating a data bit of a second state;

storage means for temporarily storing a predetermined number of consecutive bits in a predetermined number of consecutive lines of said bit map image;

means for selecting subsets of said bits forming a sample matrix of "a×b" bits, the central bit of each sample matrix being a candidate for modification;

means for convolving each said sample matrix with each said gradient mask to detect those sample matrix having an edge segment passing through their central bit, said edge segment being defined as a series of adjacent aligned data bits of the same data state forming a straight line having a single slope, and to determine the direction of a gradient change;

means for generating a set of reference bit patterns each of which includes a sub-pattern of bits corresponding to one possible combination of bits of the same data state aligned in one or more edge segments, said pattern including an "a×b" matrix of bits, a first predetermined number of bits disposed adjacent one side of said matrix, and a second predetermined number of bits disposed adjacent another side of said matrix;

means for comparing each said sample matrix having an edge segment passing through its central bit, a predetermined number of adjacent previously evaluated bits, and a predetermined number of adjacent yet to be evaluated bits to each pattern of at least a sub-set of said set of reference bit patterns;

means for generating, for each match found to a reference pattern including a predetermined type of segment transition, a modification signal for modifying the central bit of said sample matrix dependent upon the type of transition detected;

means for combining each said modification signal with its corresponding multi-bit data term to generate a compensated value signal;

means responsive to said compensated value signal and operative to generate a compensated signal pulse which during at least a portion of its period is of a first data state, or is of a second data state for the duraction of its period;

means for converting each said multi-bit data term into a corresponding percent gray signal; and

means for determining whether or not each said compensated signal pulse is of said first data state and for transmitting each said compensated signal pulse of said first state to a print or display apparatus to develop a corresponding output, but if said compensated signal pulse is of said second state, then causing the corresponding percent gray signal to be transmitted to the print or display apparatus to develop a corresponding output.

32. Apparatus for enhancing the output of a print or display apparatus as recited in claim **31** wherein said means for convolving includes:

edge detector means for detecting the existence of an edge segment in a sample matrix, and

segment change detection means for detecting a segment change within the sample matrix.

33. Apparatus for enhancing the output of a print or display apparatus as recited in claim **32** wherein said segment change detector includes vertical segment change detecting means and horizontal segment change detecting means.

34. Apparatus for enhancing the output of a print or display apparatus as recited in claim **31** wherein said means responsive to includes modulation logic means

for modulating the display drive signal of said print or display device.

35. Apparatus for enhancing the output of a print or display apparatus as recited in claim 34 wherein said modulation logic means includes a plurality of programmable modulation registers for containing predetermined addressable modulation control signals.

36. Apparatus for enhancing the output of a print or display apparatus as recited in claim 35 wherein said apparatus is embodied in an application specific integrated circuit device which can be added to a conventional display device.

37. Apparatus for enhancing the output of a print or display apparatus as recited in claim 35 wherein said modulation logic means is adapted to support an external ROM/PAL containing additional predetermined addressable modulation control signals.

38. Apparatus for enhancing the output of a print or display device which produces an image in dot matrix format, comprising:

means for generating a set of gradient masks each of which represents a plurality of edge segment transition conditions and includes a matrix of "a×b" cells each cell of which is assigned a numerical weight corresponding to the relative lightness or darkness of the corresponding pixel of an image having an edge segment passing through a center pixel of the matrix;

means for generating a data signal including a plurality of multi-bit data terms representative on a pixel by pixel basis of a bit map image to be printed or displayed;

means for evaluating each said multi-bit data term, and if the value thereof is equal to or greater than a predetermined threshold value, then generating a data bit of a first state, if the value is less than said threshold value, then generating a data bit of a second state;

storage means for temporarily storing a predetermined number of consecutive bits in a predetermined number of consecutive lines of said bit map image;

means for selecting subsets of said bits forming a sample matrix of "a×b" bits, the central bit of each sample matrix being a candidate for modification;

means for convolving each said sample matrix with each said gradient mask to detect those sample matrix having an edge segment passing through their central bit, said edge segment being defined as a series of adjacent aligned data bits of the same data state forming a straight line having a single slope, and to determine the direction of a gradient change;

means for generating a set of reference bit patterns each of which includes a sub-pattern of bits corresponding to one possible combination of bits of the same data state aligned in one or more edge segments, said pattern including an "a×b" matrix of bits, a first predetermined number of bits disposed adjacent one side of said matrix, and a second predetermined number of bits disposed adjacent another side of said matrix;

means for comparing each said sample matrix having an edge segment passing through its central bit, a predetermined number of adjacent previously evaluated bits, and a predetermined number of adjacent yet to be evaluated bits to each pattern of at least a sub-set of said set of reference bit patterns;

means for generating, for each match found to a reference pattern including a predetermined type of segment transition, a modification signal for modifying the central bit of said sample matrix dependent upon the type of transition detected;

means for combining each said modification signal with its corresponding multi-bit data term to generate a compensated value signal;

means for combining each said modification signal with its corresponding multi-bit data term to generate a compensated value signal;

means responsive to each said compensated signal pulse and operative to cause a gray scale print or display apparatus to develop a corresponding output, but in the absence of a compensated value signal, responsive to the multi-bit data term and operative to cause the gray scale print or display apparatus to develop a corresponding output.

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